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F-111 Adhesive Bonded Repairs Assessment Program - Progress Report 1: Analysis of FM300 Repairs

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Defence Science and Technology Organisation

DSTO-TR-2849

ABSTRACT

It is estimated that over 5,000 adhesively bonded repairs (ABRs) have been applied to the Royal Australian Air Force (RAAF) F-111 aircraft over the last twenty five years, mainly to honeycomb sandwich panels. Retirement of the fleet in December 2010 presented a unique opportunity to evaluate the integrity of a large number of airworthy ABRs. Consequently, DSTO in partnership with the RAAF, through ASI at DGTA and with the assistance of Boeing Australia developed a program to assess the condition of the F-111 ABRs. The F-111 Adhesive Bonded Repair Assessment Program (FABRAP) was established in mid 2010 and initial field testing was carried out from October 2010. The current report provides an update on the analysis of the results from the field level testing undertaken between October 2010 and May 2011 on repairs to honeycomb structure which used FM300 adhesive and RAAF approved surface treatments and application procedures.

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F-111 Adhesive Bonded Repairs Assessment Program - Progress Report 1: Analysis of FM300 Repairs

Executive Summary

Adhesive bonded repair technology (ABRT) has been used extensively by the Australian Defence Force (ADF) for the through-life-support of secondary and tertiary aircraft structures, where failure of the repair would not result in structural failure of the aircraft. This has resulted in significant cost savings and increased aircraft availability. Wider adoption of ABRT, particularly on primary aircraft structure that is critical to the safety of the aircraft, has the potential to increase these benefits.

A major impediment to the adoption of ABRT for primary aircraft structure is the difficulty in obtaining airworthiness certification. The two major reasons for this are:

- the lack of a non-destructive inspection (NDI) technique that can assess the in-service integrity of a bonded joint, and
- uncertainty regarding the environmental durability of adhesive bonds.

It is estimated that over 5,000 adhesively bonded repairs (ABRs) have been applied to the Royal Australian Air Force (RAAF) F-111 aircraft over the last twenty five years, mainly to honeycomb sandwich panels. Retirement of the fleet in December 2010 presented a unique opportunity to evaluate the integrity of a large number of airworthy ABRs.

Consequently, the Defence Science and Technology Organisation (DSTO) in partnership with the RAAF, through Aircraft Structural Integrity (ASI) Program at the Director General Technical Airworthiness (DGTA) and with the assistance of Boeing Australia developed a program to assess the condition of the F-111 ABRs. The F-111 Adhesive Bonded Repair Assessment Program (FABRAP) was established in mid 2010 and initial field testing was carried out from October 2010. The primary aim of FABRAP was to evaluate the environmental durability of the adhesive bonded repairs applied to F-111 honeycomb panel structure in which processes, materials and technical training were based on methods prescribed in DEFAUST9005 and detailed in AAP7021.016-1 and AAP7021.016-2.

The current report provides an update on the analysis of the results from the field level testing undertaken between October 2010 and May 2011. The major conclusions to be drawn from the work to date are detailed below.

The Pneumatic Adhesion Tensile Testing Instrument employed to examine the repair strength, known as the PATTI, has proved reliable for estimating bond strength and has provided good indications in cases where bond degradation has occurred. When the PATTI test results were filtered for statistically significant numbers of tests and erroneous results, it was clear that the bond strength of repairs was not affected by either service life or total accumulated hours since application. This indicates that when repairs were applied according to RAAF procedures and with qualified technicians in fit-for-purpose facilities, that bond strength will not degrade as a result of either long term environmental exposure or service exposure or both. The results from the initial analysis should provide improved confidence in the application of bonded repair technology in the maintenance of aircraft structure.

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Andrew Rider joined Airframes and Engines Division at DSTO in 1988. He has a PhD in Physical Chemistry from the University of New South Wales and is currently employed as a Senior Research Scientist with Air Vehicles Division. He is involved in research to support RAAF maintenance of bonded structure and application of repairs used on ADF aircraft.

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1. Introduction

Adhesive bonded repair technology (ABRT) has been used extensively by the Australian Defence Force (ADF) for the through-life-support of secondary and tertiary aircraft structures, where failure of the repair would not result in structural failure of the aircraft. This has resulted in significant cost savings and increased aircraft availability. Wider adoption of ABRT, particularly on primary aircraft structure that is critical to the safety of the aircraft, has the potential to increase these benefits.

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The current report provides an update on the analysis of the results from the field-level testing undertaken between October 2010 and May 2011, with details of the testing phases provided below. In this first progress report on the statistical analysis of results from the field trials, analysis has been limited to bonded repairs in which FM300 adhesive was used. FM300 has a distinctive blue colour which is unique for F-111 repairs and it is known that the adhesive was introduced for bonded repairs at the time the current bonding procedures prescribed in DEFAUST9005 [1] became established in RAAF bonded repairs at RAAF Amberley.

2. Test Phases and Background

A brief background to the typical repairs examined and the strength testing and analysis methods employed is provided. F-111 structure is comprised of large areas of honeycomb-core stiffened aluminium panels, which exist across the fuselage and are used for most control surfaces. The honeycomb panels typically are manufactured by adhesively bonding an upper and lower aluminium skin to aluminium honeycomb-core. The structure provides added stiffness to the airframe and reduces the weight of control surfaces, but is prone to impact damage. To re-establish airworthiness of an impact-damaged component, one of the typical repair techniques requires removal of the damaged skin and honeycomb core. New core is adhesively bonded back in place and an aluminium doubler of similar thickness to the skin thickness is bonded over the exposed core with a prescribed overlap length (Figure 1). The purpose of the bonded repair analysis program was to interrogate the condition of the adhesive bond between the bonded doubler and the existing aluminium skin. The method for bonding the skin used processes and materials defined in DEFUST9005 [1] and AAP7021.016-2 [3] RAAF Air Publications and special purpose facilities at RAAF Amberley with trained technicians. The condition of the doubler-bond provides an opportunity to establish the reliability of the bonding processes used and their resistance to typical service environments experienced by F-111 aircraft in Northern Australia.

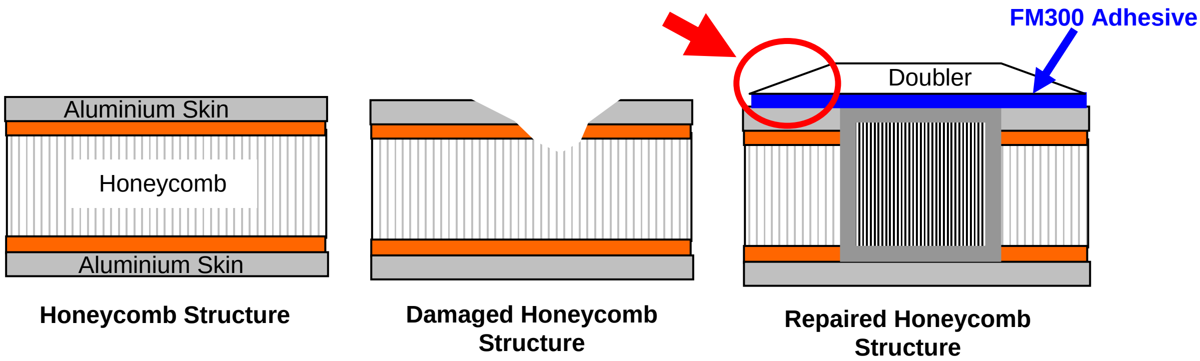


Figure 1 Typical honeycomb structure present on F-111 and common repair techniques used to re-establish airworthiness. The highlighted area in red indicates the focus of the bonded repair program, in which the adhesive bond of the applied doubler to the existing aluminium skin is interrogated to determine condition after service exposure.

The primary method used to interrogate the strength of the bonded doubler was with a Pneumatic Adhesion Tensile Testing Instrument (PATTI) [4]. Half-inch diameter stubs were bonded to the aluminium skin followed by a hole being routed out around the outside of the stub, through the doubler thickness. A piston attached to the stub was then pressurised and the burst pressure recorded (Figure 2). The pull-off tensile strength was then calculated and recorded. Depending on the repair location and size, between 1 and more than 10 test stubs may have been used to estimate the repair residual-strength. Subsequently, the doubler was peeled from the panel surface and photographed to determine if any anomalous areas existed.

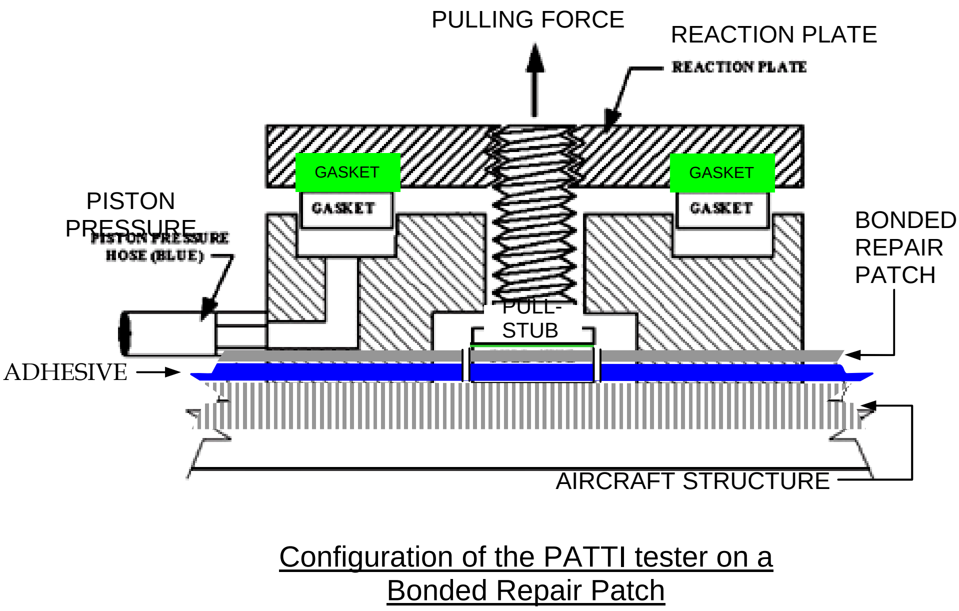


Figure 2 Pneumatic Adhesion Tensile Testing Instrument (PATTI) used to interrogate the residual strength of the bonded repairs on F-111 honeycomb stiffened structure

Phase 1 testing was undertaken from the 25th of October to the 3rd of December, 2010 at RAAF Base Amberley. Phase 1 methods have been documented previously [5]. Phase 2 testing was undertaken from the 16th to the 27th of May, 2011 at RAAF Base Amberley. The test procedure was identical to that used in Phase 1. Additionally, many smaller panels that had been removed from the aircraft were sent to DSTO-Melbourne for more detailed inspections.

Phase 3 testing covers all work performed at DSTO Melbourne on panels that had been removed from the aircraft. Phase 3 testing commenced in May 2011 and is still underway.

3. Method

3.1 PATTI Testing of Adhesively Bonded Repairs

The test method used in Phase 2 was very similar to that used in Phase 1, and summarised below. The method is explained in more detail in reference 5.

1. Identify potential repairs to be tested. Remove sealant from the edge of repair, and verify that the adhesive corresponds to a DEFAUST9005 compliant repair.
2. Where possible, perform non-destructive inspection (NDI) on repairs.
3. Photograph repairs, showing any NDI indications.

4. Determine regions for portable adhesion testing using the Pneumatic Adhesion Tensile Testing Instrument (PATTI).
5. Route out the doubler test area for each stub used in the PATTI test.
6. Clean and abrade area for testing then bond on test stubs using EA9309.3NA paste adhesive.
7. Perform PATTI® testing with Elcometer 110 PATTI® to measure flatwise-tension strength of the bond
8. Photograph failure surfaces and place the stubs in sealed, labelled bags
9. Remove doubler using a wedge and pliers or multigrips
10. Photograph repair failure surfaces and place doublers in a sealed, labelled plastic bags.

The test method used in Phase 3 is identical to that described above, except that the NDI techniques included radiography, ultrasonic A-scan, and a technique such as Bondmaster, as well as tap testing. These results will be reported in a future publication.

3.2 PATTI Testing Variability Assessment

Due to the variable geometry of the honeycomb panels examined and the wide range of locations for the bonded repairs, the PATTI testing was conducted using different configurations, which potentially could alter the strength measurement. For example, when a repair stub was bonded to a curved surface, packer plates were used to provide a level surface for the piston to react against, however, perfect alignment was not always guaranteed. Additionally, as the panels had varying skin thicknesses, there was the potential for the skin to deflect during the application of the tensile loading of the stub. The deflection can lead to higher stresses at the edge of the stub and potentially reduce the measured strength. In order for a reasonable estimate of these factors to be accounted for in the likely range of measured strengths, a series of empirical laboratory tests were conducted to determine upper bounds on misalignment and skin deflection effects. It was reasoned that a laboratory prepared bond would represent an undegraded bond and the lower strength ranges measured would be representative of geometrically induced effects that were responsible for lowering the "true" strength of the repairs measured in the field. It should be noted the "knock-down" in strength created by misalignment or skin deflection effects was only considered relevant when the repair exhibited cohesion failure of the adhesive bondline during fracture. In cases where large areas of "adhesion" failure were observed, or other unusual features such as high porosity were evident, then these repairs were considered representative examples of in-service degradation or problems in repair application. The terms "cohesion" and "adhesion" failure are used to describe fracture within the adhesive layer or fracture at the interface between the adhesive and metal surface, respectively.

3.2.1 Effect of Piston Misalignment

Half inch (12.5 mm diameter) test stubs were bonded to a 3.2 mm thick Al 2024-T3 plate, using the grit-blast and silane surface cleaning and bond preparation method [3]. The stubs were bonded with FM300 adhesive with the application of a low level of pressure by using a second flat plate placed evenly over the stubs, and a deadweight placed on top of this plate. The adhesive was heated from room temperature to 180°C using a ramp rate of 3°C/min, held at temperature for 90 minutes (to take into account lag time in heating), then cooled to below 50°C before being handled. The first set of 24 stubs were bonded using adhesive that had been staged for 20 minutes at 80°C, to reduce the volatile level in the adhesive before cure. A second set of 24 stubs was bonded without adhesive staging to verify the effect on measured bond strength and reproducibility of the overall manufacturing and testing processes.

When the PATTI unit is used on real aircraft panels that are curved, the piston may be seated at an off-normal angle to the test stub. To simulate this, packers were wedged underneath the piston, approximately 20 mm in from the edge. The piston was the F-16 piston with a reaction area of 16 square inches. Four packer thicknesses were used, as shown in Figure 3, to simulate a situation where the piston seats at the following angles:

- 0.508 mm (0.02”) = 0.27°
- 1.6 mm (0.63”) = 0.86°
- 3.2 mm (0.125”) = 1.7°
- 6.4 mm (2 x 0.125”) = 3.4°

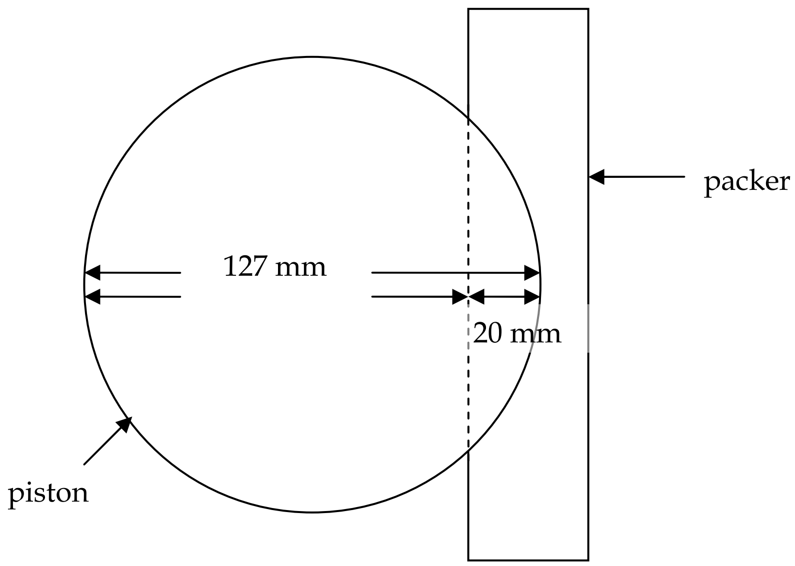


Figure 3 Schematic diagram showing top view of PATTI piston with a packer underneath one side to simulate an off-angle test

3.2.2 Effect of Substrate Thickness and Testing Rate

Half inch (12.5 mm diameter) test stubs were bonded to aluminium 2024-T3 clad plates, of 3.2 mm and 1.6 mm thickness. The surfaces were prepared using the grit-blast and silane method [3], and using unstaged adhesive, bonded in an oven using deadweight pressure in the same way as the angled piston specimens of Section 3.2.1. The stubs were tested in an Instron 5500R static test machine at three rates of crosshead extension; 0.2 mm/min, 2.0 mm/min, and 8.0 mm/min. The test fixture consisted of a rigid plate with a one-inch diameter hole that was bolted to the test-machine crosshead, and a loading nose fixed to the top of the load frame, into which the test stub could be screwed. This simulates the use of a PATTI piston, with the one-inch diameter recess at the base of the piston.

4. Results and Discussion

4.1 PATTI Testing Variability Assessment

4.1.1 The Effect of Piston Misalignment and Bondline Porosity

Figure 4 shows the relationship between PATTI strength and the angle of piston to the test surface. Stubs in the first set used staged adhesive. At a 5.1° piston angle, the gasket popped out of the piston before sufficient pressurisation was reached to achieve stub failure. It is unlikely that field experiments would have been able to undertake any tests with a piston angle much greater than 3.4°. If 3.4° is taken as the maximum practical angle that the piston could have achieved, then it appears that when the substrate thickness is 3.2 mm, a pristine stub could fail at loads as low as 15 MPa due to potential off-angle loading effects of the piston. It is also noteworthy that as the piston misalignment increases, the degree of variation in the measured PATTI strength increases significantly. If this variation is considered, then values approaching 10 MPa are possible in the worst case for a repair which had not experienced any significant strength degradation.

Figure 5 shows the failure surfaces from a 0° test from the second set. This type of failure was not uncommon, with what appears to be adhesion failure in a ring around the edge of the stub. As the test specimens were carefully manufactured and tested in controlled laboratory conditions, the adhesive having been cured and tested within 24 hours and not exposed to any degrading environment, adhesion failure is unlikely. It is possible that this failure surface shows the effect of peel, where the adhesive tends to remain bonded to the stiffer stub and peels away from the more flexible substrate due to the highest strain in the adhesive occurring at the edge of the adhesive layer, close to the flexible substrate.

The failure surfaces of stubs prepared with unstaged adhesive (Figure 5) showed high levels of bondline porosity. General observation of a large number of stubs from tested repairs indicated that bondline porosity was prevalent and could be quite high. The porosity is expected given most repairs were conducted using vacuum bag pressurisation. The results in Figure 4 indicate that porosity may not have any effect on the strength of an undegraded repair. However studies were not performed to assess the effect of bondline porosity on environmentally degraded repairs.

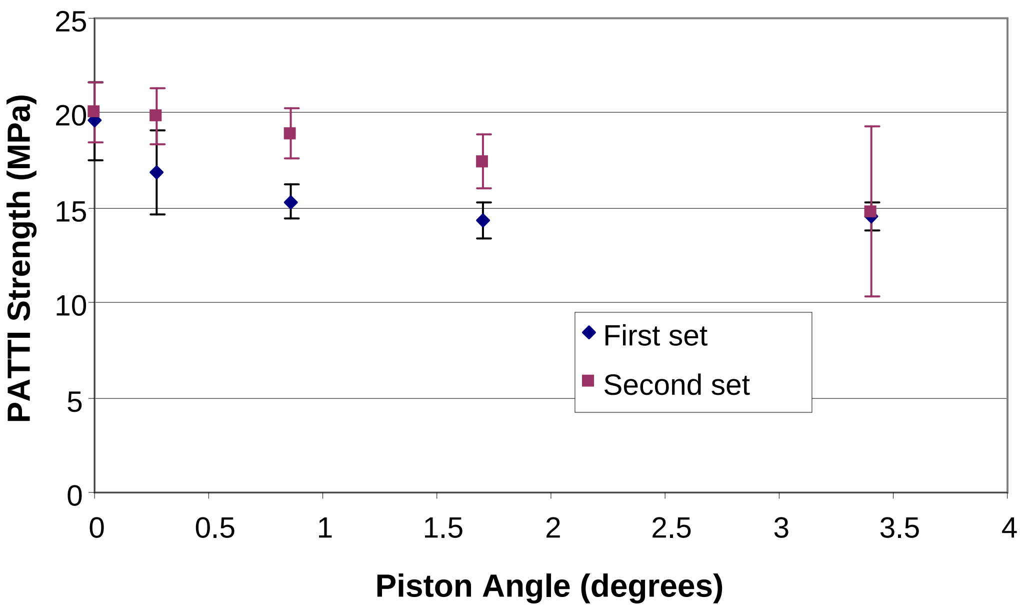


Figure 4 Relationship between PATTI strength and the angle of piston to the test surface. Stubs in the first set used staged adhesive.

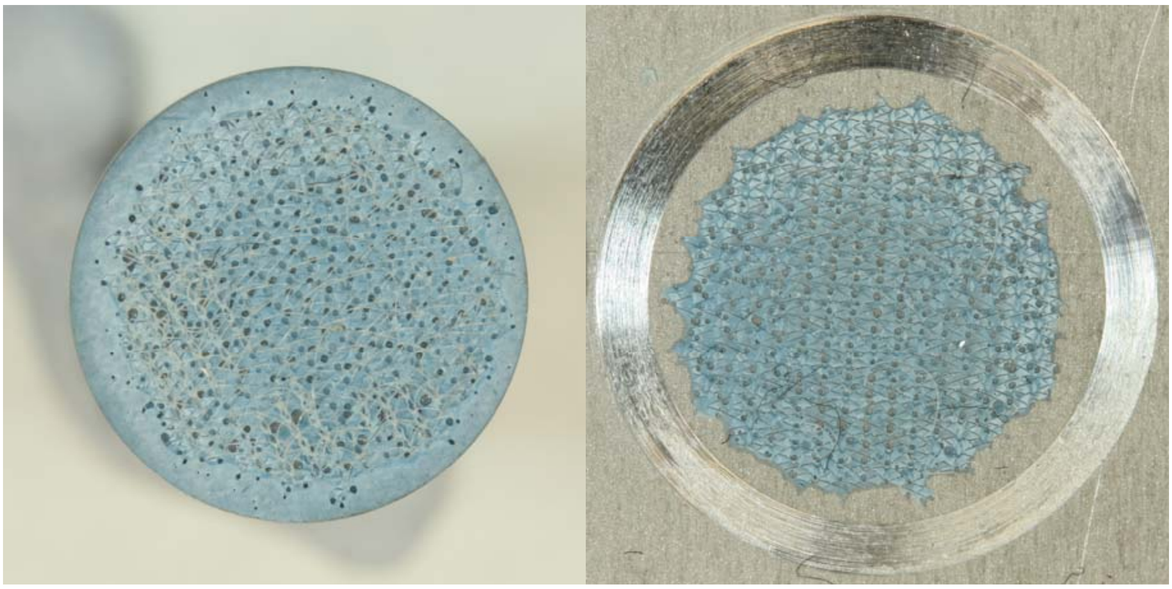


Figure 5 Failure surfaces from a 0° test from the second set with the stub on the left and the substrate on the right. The apparent adhesion failure may actually be the effect of peel in the test configuration. Note that this failure surface shows quite a lot of small voids, which is typical of unstaged adhesive.

4.1.2 Effect of Strain Rate and Variable Skin Thickness

The PATTI test manual recommends that the rate of piston pressurisation be set such that the stubs reach 50 psi between 28 and 50 seconds of commencement of the test. This is an effort to standardise the rate of loading, or strain rate. During FABRAP field testing there was quite a large variation in time to failure, resulting in large variations in strain rate, which was due to inconsistencies in the test equipment. Polymeric materials tend to exhibit strain rate sensitivity in mechanical testing due to viscoelastic effects. Higher strain rates during testing generally increase the measured strength.

Epoxies are often considered strain rate insensitive due to the extensive crosslinking in the chemical structure, which minimises the level of viscoelasticity compared with thermoplastic materials. This appears to be supported by the test results shown in Table 1, which show that although the tensile strength of the test pieces appears to increase with increasing strain rate, as expected, the increase is small and is within the scatter of experimental results.

Table 1 Effect of substrate thickness and strain rate on pull-off tension strength measured using the geometry representative of the PATTI

Substrate Thickness (mm)	Loading Rate (mm/min)	Tensile Strength (MPa)	Standard Deviation (MPa)	Time to Failure (sec)
3.2	0.2	21.8	1.8	150
3.2	2.0	21.5	2.4	15.5
3.2	8.0	23.2	2.9	3.8
1.6	0.2	8.63	0.91	125
1.6	2.0	8.84	0.75	14
1.6	8.0	9.58	0.89	3.2

However, substrate thickness appears to have a pronounced effect on the PATTI strength, with stubs bonded to the thinner substrate having a significantly lower strength. There did not appear to be a change in the appearance of the failure surfaces when the substrate thickness was varied from 3.2 mm to 1.6 mm, with a typical failure surface appearing similar to that shown in Figure 5, although the area exhibiting adhesion failure was generally smaller.

Independent testing suggests that PATTI tests of stubs bonded to substrates as thin as 0.7 mm, may exhibit a much larger proportion of adhesion failure, with adhesion failure mainly in the middle of the stub rather than at the edge [6]. An examination of the FABRAP repairs shows that the component skin thickness in the vicinity of some repairs may be as low as 0.3 mm. Further tests may be required to check the effect of thinner substrates on the PATTI strength. However, this work indicates that a pull-off strength around 10 MPa or higher may occur for an adhesive bond which has been applied correctly and that has not undergone any degradation due to environmental exposure. In contrast, a pull-off strength below 10 MPa is likely to have a higher probability that the bond strength is compromised, either through inadequate application or through degradation resulting from exposure to service conditions. Although the test results in Table 1 indicates that PATTI tests of stubs bonded to thinner substrates may exhibit lower strength than the 10 MPa cut-off, however, when allowing for experimental error, PATTI strengths of 10 MPa or below highlight when more detailed analysis of individual stub results is required.

Note that this stiffening effect is not isolated to variation in substrate thickness, but can be extended to stiffening caused by other structure in the vicinity of the test stub. The aircraft skins are bonded, bolted or riveted to other parts such as frames, stiffeners and opposite face skins. These all have the effect of stiffening the structure in the local region, and this effect should also be taken into account.

In conclusion, the results from section 4.1 provide a good indication of a reasonable lower bound for PATTI testing conducted on pristine adhesive bonds with configurations representative of the F-111 honeycomb panels examined. In cases where bondline porosity exists and geometrical alignment is unfavourable, together with deflection of thin skins, it may be possible for pull-off strengths as low as 10 MPa to be measured. However, as indicated previously, it is also necessary to inspect the failure surfaces from stub tests to ensure cohesive fracture of the adhesive bondline has occurred. This will confirm pull-off strength values around 10 MPa or higher are unlikely to have degraded significantly in strength due to “adhesion” failure.

4.2 PATTI Testing of F-111 Adhesively Bonded Repairs

The majority of repairs inspected during FABRAP were manufactured using Cytec FM300 or Cytec FM300-2K structural film adhesive. A few inspected repairs used Cytec FM73 structural film adhesive, or a grey paste adhesive that was most likely Hysol EA934. Because of the small numbers of FM73 and EA934 repairs, they have been excluded from the data set as the population is statistically insignificant and the processes applied using these adhesives is not known with confidence. This report examines FM300 in detail, with FM300-2K repairs examined in a future report. Figure 6 shows the distribution of repair strengths of all 236 FM300 repairs. The repair strength is assessed on the basis of the average pull-off tension strength measured using the PATTI test for each repair. The average strength may involve between one and more than ten pull-off tests on a given repair. The number of tests conducted per repair was heavily dependent on the repair size. Consequently, smaller repairs may only have a single pull-off test and tend to distort the overall results, particularly, in cases where high curvature angles could make a single test quite variable. On this basis, a decision was made to exclude results where a repair measurement was based on only a single test conducted on a repair. The expectation was that these results from single PATTI tests would contain statistical uncertainty that could unreasonably skew the overall trend in data.

Figure 7 shows the strength distribution of the bonded repairs that had a traceable service history, with repairs based on a single test removed. The overall distribution in strength is similar to the total population set and provides some confidence that trends observed for the smaller dataset with recorded history would be representative of a significantly larger repair population.

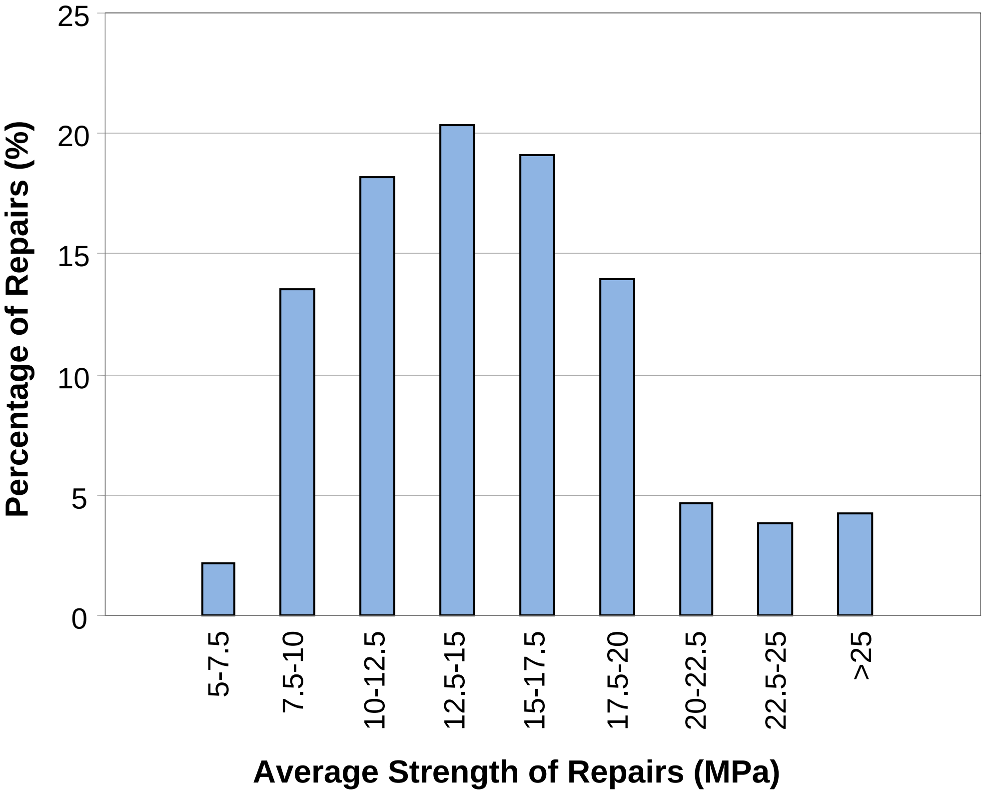


Figure 6 The distribution of repair strength for the 236 FM300 repairs tested during the bonded repair trial

The benefit of the current testing method, in which the PATTI stubs were specifically located as close to the edge of the doubler as possible, also provides a method which helps to remove any effects that repair size may have on the analysis (Figure 8). By placing the stubs at the doubler edges, the bondline area being interrogated should experience similar environmental conditions, irrespective of the overall repair size. The test location also examines the area of the doubler that would have experienced the greatest environmental exposure and, therefore, provides a measure of the maximum effect that moisture and the environment may have had on the bond strength. It should be noted that the moisture only has access to the bondline from the edges of the repair either through the adhesive layer or the adhesive/aluminium interfaces or both.

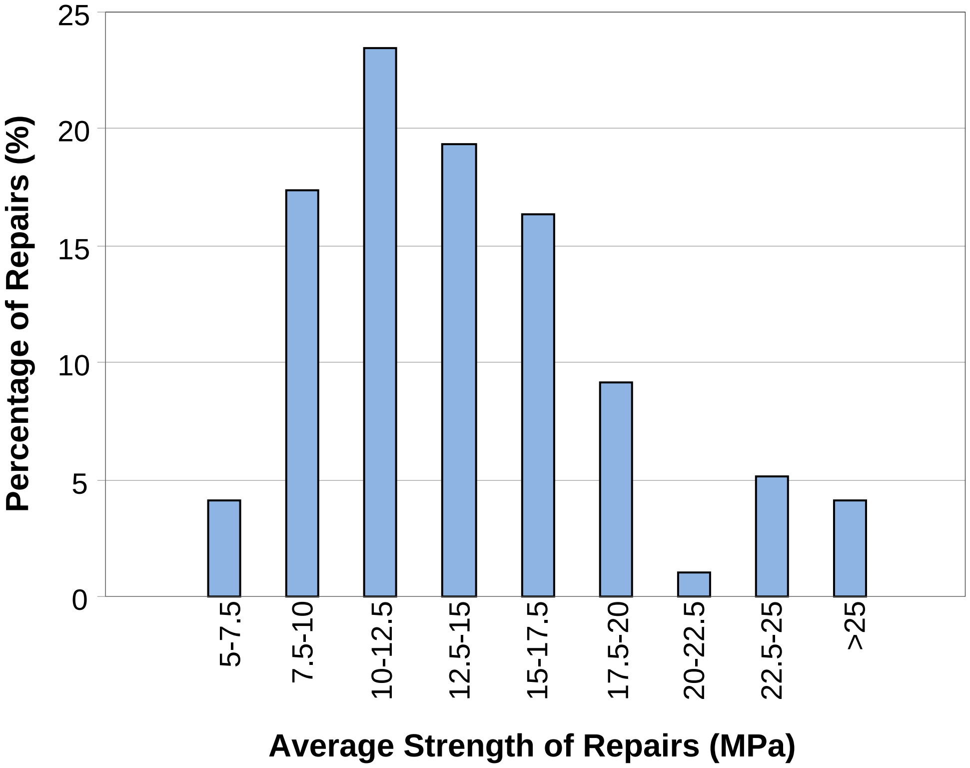


Figure 7 *The distribution of repair strength of FM300 repairs in which records detailing the repair application processes, dates of application and service history are available. There are 98 FM300 repairs.*

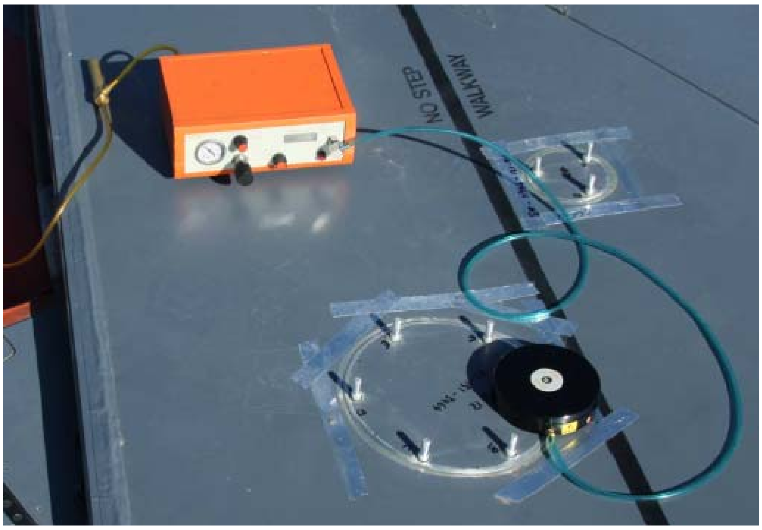


Figure 8 *Examples of stub positions on repairs of different sizes, illustrating that the PATTI test will examine similar regions of bondline for both cases where environmental exposure would be expected to have had the greatest potential to affect the bondline integrity.*

This current report details statistical analysis of repairs that used FM300 adhesive. A range of variables were examined to determine if any significant factors affected repair strength. The major factors examined included the following:

- Repair location on the aircraft structure, such as upper, lower or side surface
- Repair age based on either total accumulated time or total number of flight hours since application
- The influence of substructure stiffness, primarily the effect of panel skin thickness.

4.2.1 The Effect of Repair Location

The location of each repair was marked on drawings of the F-111 aircraft, shown in Figure 9, below. Note that repairs to horizontal stabilisers (HSTABs) were not included in the diagrams, as the large number of repairs on these components could not be accurately represented on a single diagram. Repairs to pavetack doors also were not included as the pavetack door differs in shape to the weapons bay doors shown in the diagrams. The size of each marking roughly indicates the size of the repair it represents and the colours represent the average repair pull-off strength as indicated:

Red	lower than 10 MPa
Orange	10-15 MPa
Yellow	15-20 MPa
Green	greater than 20 MPa

Close inspection of the location of the seven low strength (red) repairs suggests that most were located on components which had a higher degree of surface curvature. The low strength repairs were on panel 3208 (RHS) (two repairs), the rotating glove panel (panel 3424 upper surface), panel 3425 (upper surface), panel 3111, the inboard leading edge flap (upper surface), and the saddle tank. As most of the repairs analysed existed on the upper surface of the aircraft, it is not possible to determine a correlation between repair location and strength. However, the HSTABs had a considerable number of repairs on upper and lower surfaces near leading and trailing edges and did not exhibit any trend in repair strength with location. The surfaces with higher degrees of curvature may have some sensitivity to measured strength due to misalignment of the piston head being more likely, as indicated in Figure 2. However, the repairs on similar components in close proximity to the low strength repairs exhibited acceptable strength, which would suggest that component geometry was not a major factor influencing the measured repair strength. Further analysis of these low strength repairs will be provided in following sections.

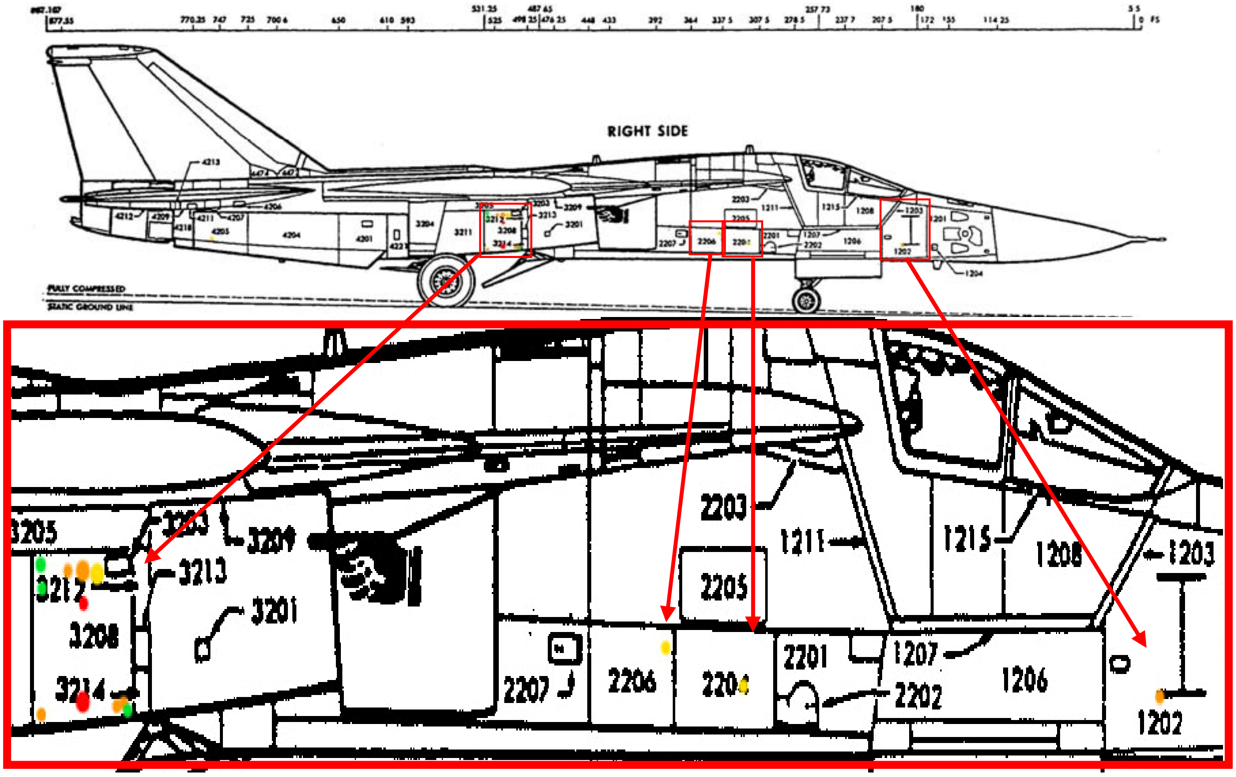


Figure 9 *Location of inspected FM300 repairs on the aircraft. Red markings denote repairs with a low strength (less than 10 MPa), orange and yellow markings represent medium strength repairs, and green markings represent high strength repairs (greater than 20 MPa).*

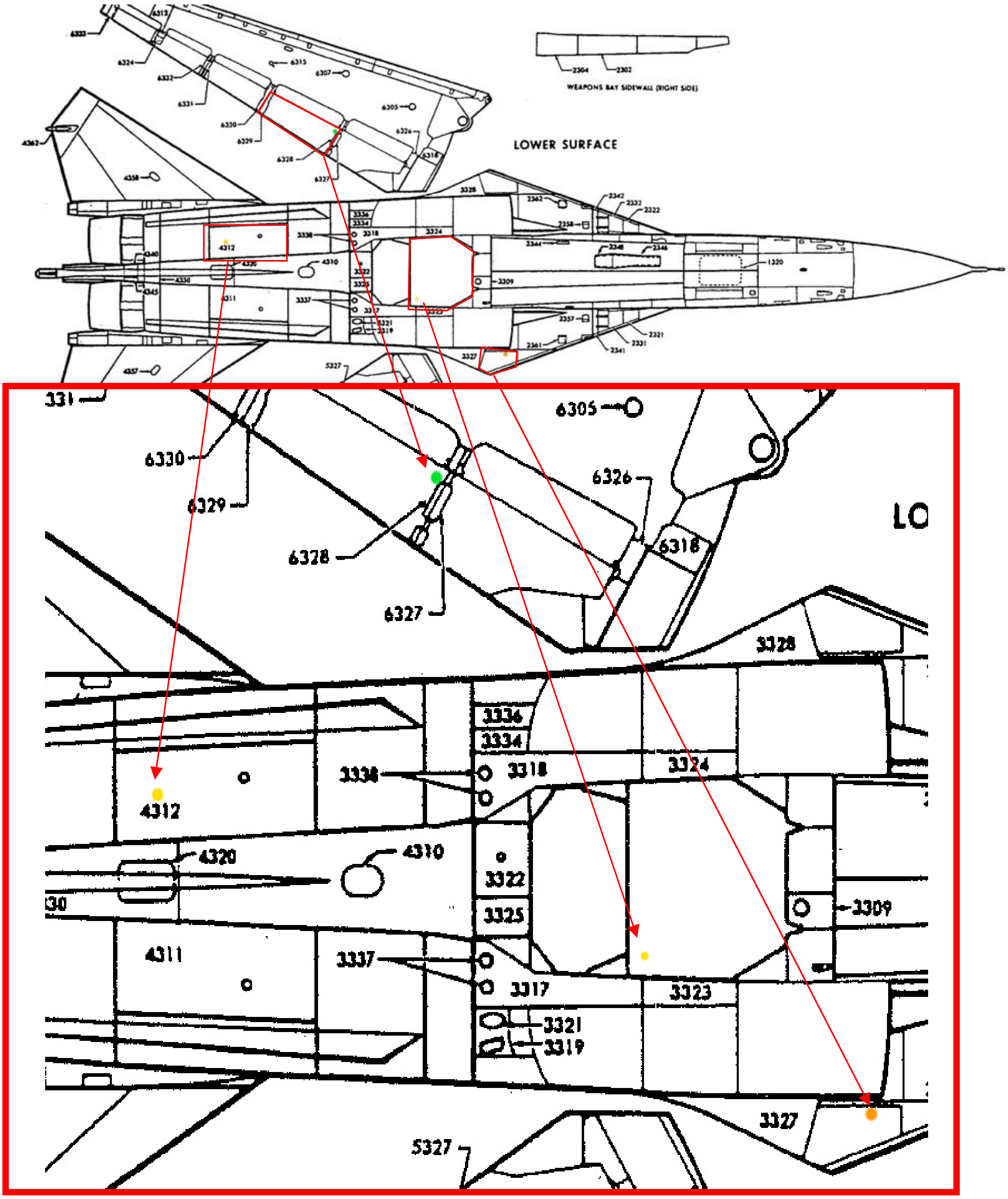
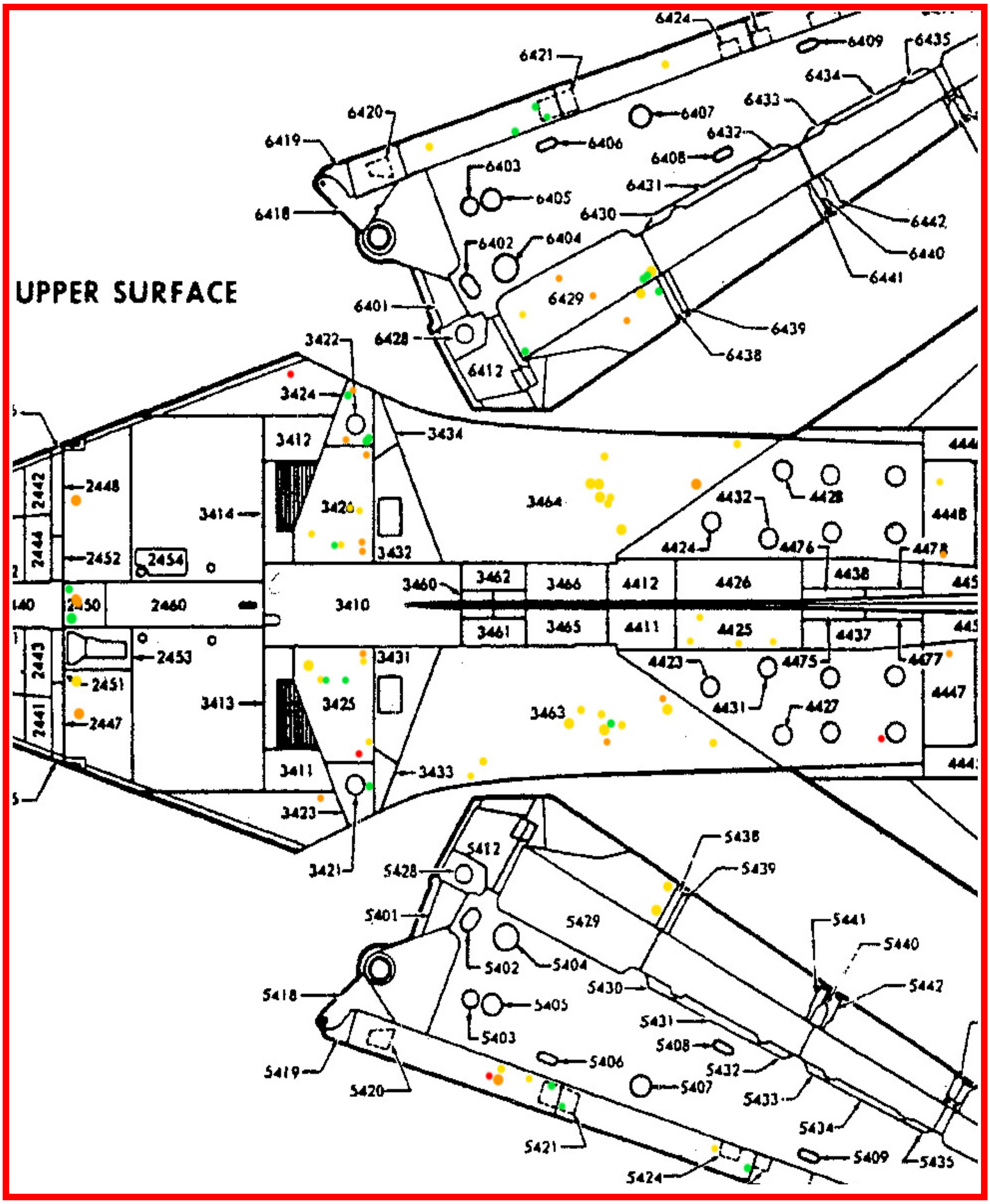


Figure 9 con't. Location of inspected FM300 repairs on the aircraft. Red markings denote repairs with a low strength (less than 10 MPa), orange and yellow markings represent medium strength repairs, and green markings represent high strength repairs (greater than 20 MPa).



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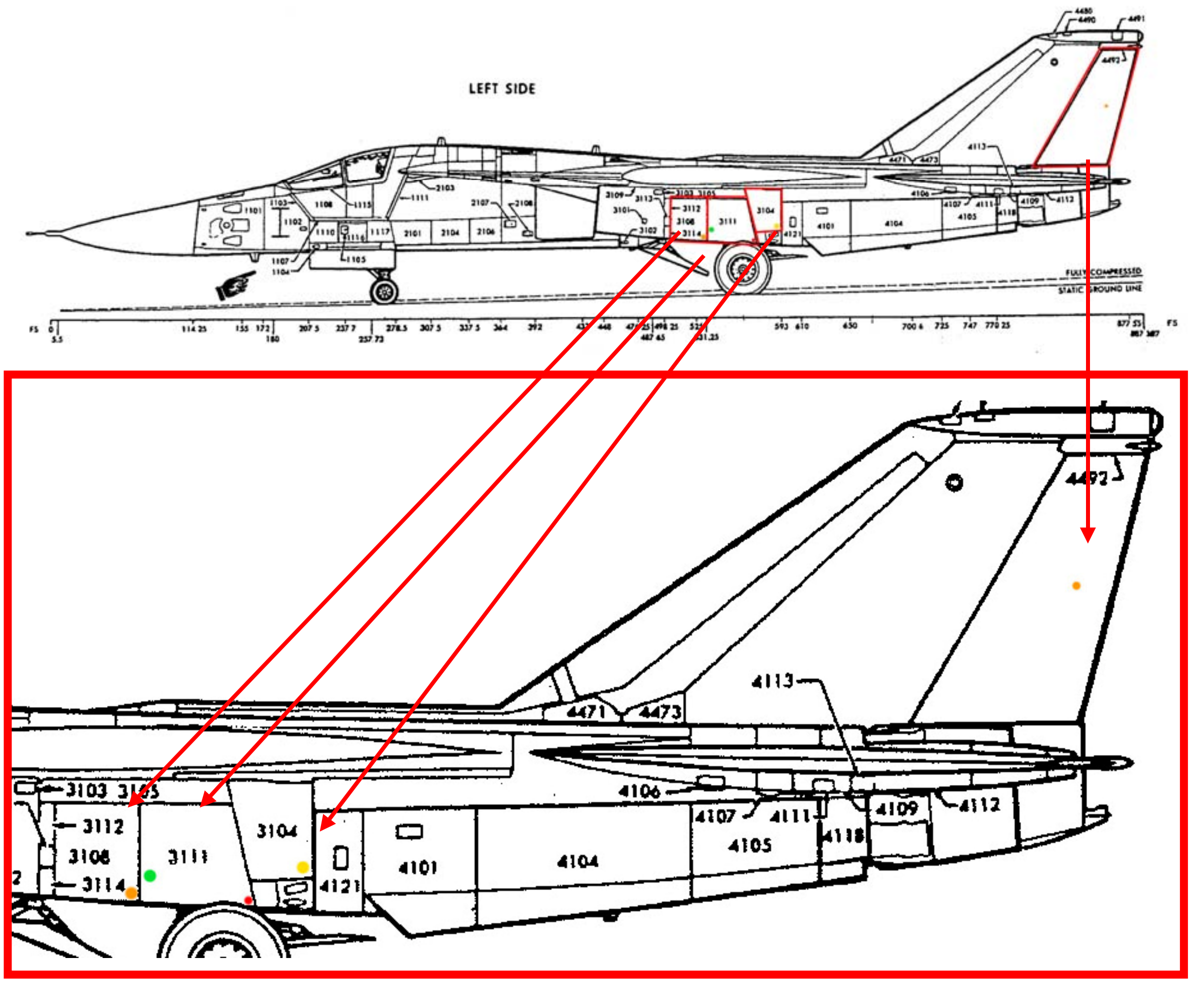

Figure 9 con't. Location of inspected FM300 repairs on the aircraft. Red markings denote repairs with a low strength (less than 10 MPa), orange and yellow markings represent medium strength repairs, and green markings represent high strength repairs (greater than 20 MPa).

4.2.2 The Effect of Repair Age and Service History

One of the hurdles to certification of bonded repairs is accurately quantifying the effect of age on the repair strength. Water compromises the bond chemistry as there is a thermodynamic driving force for individual water molecules to displace the adhesive bonds from the metallic substrate once the moisture has diffused through the adhesive bondline. Water will more rapidly diffuse through an adhesive bondline in a hot and humid service environment than in a cool, dry environment, due to the increased temperature, and the increased amount of water vapour. After extended exposure to a hot and humid environment, there is potential for the bond strength to be degraded if surface treatments and application of the adhesive bond have not been carried out correctly.

Currently, there are no available non-destructive inspection techniques to establish if the bond strength has degraded due to in-service exposure. Additionally, the strength of a recently applied bonded repair is unknown and, therefore, the reliability of the technology is also questioned. Consequently, the only way to prove the reliability and environmental resistance of a bonded repair is to destructively assess its condition after application and service. The RAAF experience provides anecdotal evidence that a large number of adhesively bonded repairs have retained their integrity after service periods exceeding 30 years, however until the current program, there has not been a comprehensive study of the residual strength of bonded repairs applied to metallic substrates using RAAF approved processes. The current program has provided an opportunity to gauge the reliability and environmental durability of adhesively bonded aluminium-doublers applied to aluminium-skins using a specific set of methods detailed in DEFAUST9005 [1] and the associated AAP7021.016-1 [2] and AAP7021.016-2 [3] RAAF Air Publications. The assessment of the bonded repairs has used a combination of in-situ mechanical tests, which provide a semi-quantitative measure of the bond strength in localised regions, combined with a visual assessment of the doubler and skin surfaces, post doubler removal. Extensive efforts were also made to correlate the inspected repairs with service history, to provide a measure of repair condition with both accumulated flight hours and total life-time of environmental exposure.

Where possible, the repairs investigated during the adhesive bond inspection program were matched with the repair paperwork completed by the bond shop at the time of repair application, although in some cases they were only matched with the paperwork that specified the design of the repair. The repair paperwork helps to date the repair, and where an engineering design existed, but there was no bond-shop paperwork, it was assumed that the repair was undertaken within two months of the design approval (evidence suggests that this is an acceptable assumption). The repair paperwork would often include information on the repair environment, such as temperature, humidity, and time taken to perform each process, which can also affect the quality of the adhesive bond. Due to resourcing constraints this progress report does not investigate the effect of the repair environment on the measured repair-strength, however, this is an area for future reporting.

Once the repairs were dated, most of them could be matched up with aircraft service histories. This is important as some components were easily interchangeable between aircraft, and when a component was removed for repair, it did not necessarily go back on the same aircraft. Sometimes repaired panels or components would be spare and stored until needed.

The initial analysis of the bonded repairs examined if a correlation existed with the average repair strength and the repair age (Figure 10). The repair age represents the total accumulated time since the repair was applied to the time the repair was tested. There is no correlation in strength with repair age as indicated by the wide distributions of strength that exist for the repairs ranging between 500 and 6000 days or around 1.5 to 16 years. The extent of variation for discrete repair ages is greater than the difference in the average value for nearly all the data.

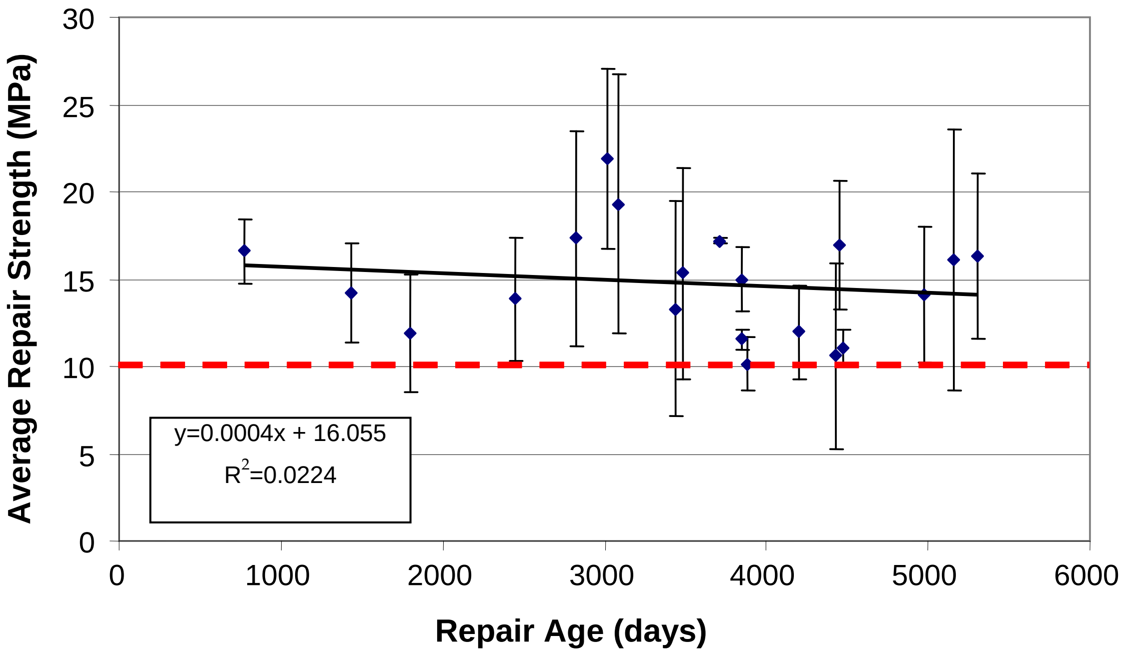

Figure 10 The average repair strength measured as a function of total age of the repair where the error bars represent the 95% confidence interval for all repairs measured with the same lifetime. The broken red line represents the lower limit expected for undegraded bonds accounting for possible geometrical variations in loading.

Figure 11 indicates the average repair strength as a function of accumulated flight hours. The data is similar to Figure 10 and shows that the strength does not depend on the accumulated flight hours, with the variation of repair strength at discrete times being typically greater than the average strength over period between 100 and 1600 hours.

The results from both Figure 10 and Figure 11 suggest that it is equally likely that a repair randomly measured for strength over a period of at least 6000 days of total life or 1600 hours flight time or both will have an average strength around 15 MPa with a 95% confidence interval around ±4 MPa. These initial results are quite encouraging as they show that with 95% confidence, a minimum strength around 11 MPa would be expected for the total lifetime of the repairs examined. This is above the 10 MPa lower limit which is possible when accounting for variation in bondline strength that would simply be due to geometrical loading effects, discussed above in Section 4.1. Clearly, the average results also contain individual repairs where the strength was below 10 MPa and further analysis of these repairs is undertaken in following sections.

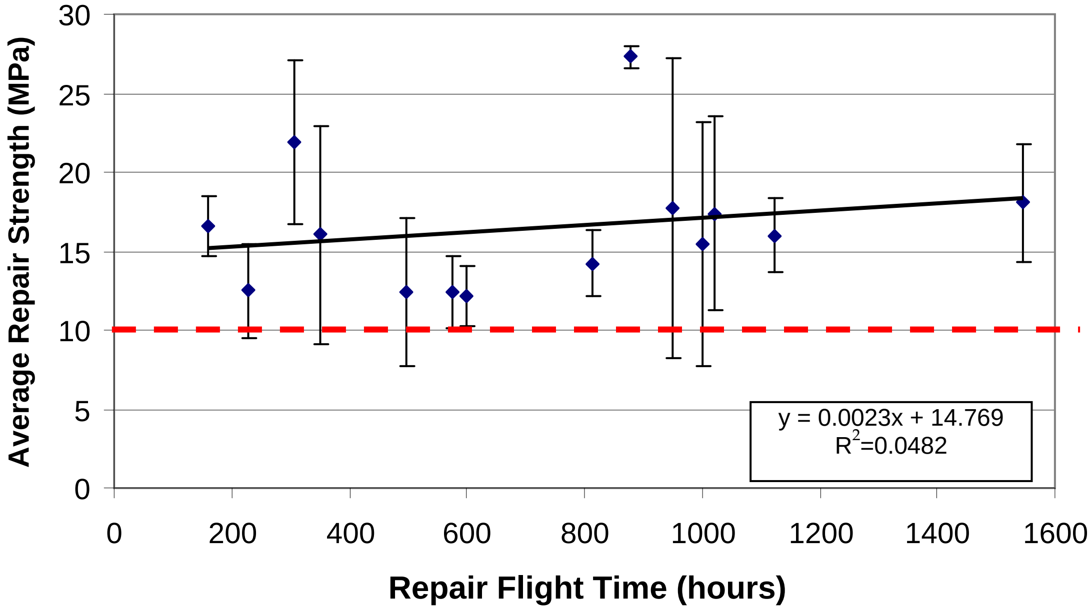

Figure 11 Correlation between flight hours experienced by each repair and average repair strength, where the error bars represent the 95% confidence interval for all repairs measured with the same accumulated flight hours. The broken red line represents the lower limit expected for undegraded bonds accounting for possible geometrical variations in loading.

4.2.3 The Effect of Structural Stiffness

Section 4.1.2 demonstrated that the stiffness of the repaired structure can affect the measured PATTI strength. Typically, the repair doubler is the same thickness as the aircraft skin on which it is applied, although this is not always true as aircraft skins tend to increase in thickness towards the edges of panels. The doubler thicknesses of selected repairs were consequently measured physically and optically and compared with the measured strength, shown in Figure 12, to establish if there was a tendency for thicker doublers, and therefore thicker substrates, to provide higher strength. The results show that, allowing for the variation in strength data for skin thicknesses of similar values, there is a direct correlation. As there is considerable variation in individual repair strengths at given thicknesses, the correlation is not strong, but certainly shows that skin thickness influences the measured strength. This finding supports the general assumption that geometrical loading effects experienced during PATTI testing could lead to minimum strength values for undegraded bonds approaching 10 MPa.

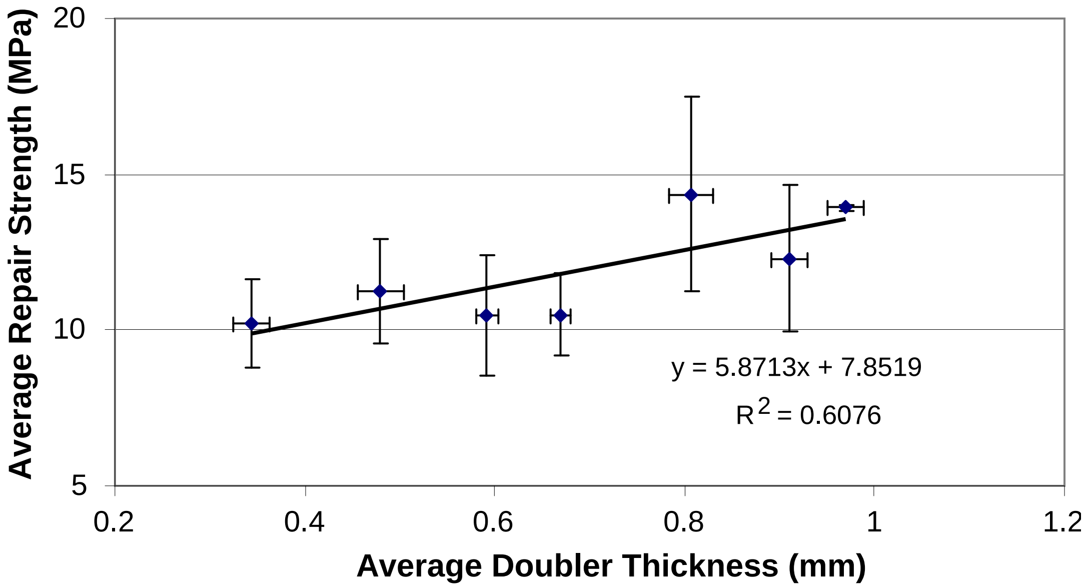

Figure 12 The influence of average repair strength as a function of repair doubler thickness

4.2.4 Further Data Interrogation

Further analysis of the data set examined those data points that exhibited some of the lowest strengths. Some of these data points could be excluded from the data set under investigation. These data points are described in more detail in Table 2.

Table 2 Details of individual test stub result examinations and reasons for either including or excluding the measured PATTI strength from the overall dataset

Repair Stub ID	Explanation for Anomaly	Decision	Reason
DSTO-04-03	Stainless to Aluminium Repair created a galvanic couple	Remove from dataset	Repair damaged during service and damage identified but not repaired
G14-117-18	Small doubler over injection repair	Remove from dataset	Stub tested on low strength potting resin unrepresentative
DSTO-06-01B	Stub placed over impacted damage region of repair	Remove from dataset	During service impact damaged repair would be replaced. Strength reduction not due to bond degradation
G14-117-06A	Repair placed over foaming adhesive flash	Retain in dataset	Representative of possible oversight in application
A8-143-01D, E,F	Stub bonded to composite material	Remove from dataset	Program not designed to interrogate composite bonding, non-representative
A8-514-10C	Stub bonded over rivet	Remove from dataset	Not representative of adhesive to aluminium bond prepared by standard methods
A8-512-15C	Stub bonded to potted repair	Remove from dataset	Not representative of adhesive to aluminium bond prepared by standard methods

After the individual test stubs detailed in Table 2 were excluded, repairs with only one stub were also removed from the data set, as one data point per repair does not provide a significant statistical distribution. Additionally, as discussed above, as the repair area being interrogated is at the very edge of the repair, the strength of repairs with small and large doublers should be equivalent as they will have been exposed to moisture for equivalent times. Consequently, the data set of FM300 repairs reduced to 163 repairs from the original 236. Figure 13 shows the distribution of average repair strength in the modified data set for each aircraft or from specific storage locations in which DSTO had recovered the paperwork, denoted as DSTO-01, -02, 06. It can be seen that only A8-143 has repairs where the spread in strength, which is represented by the 95% confidence limit error bars, drops below the 10 MPa limit.

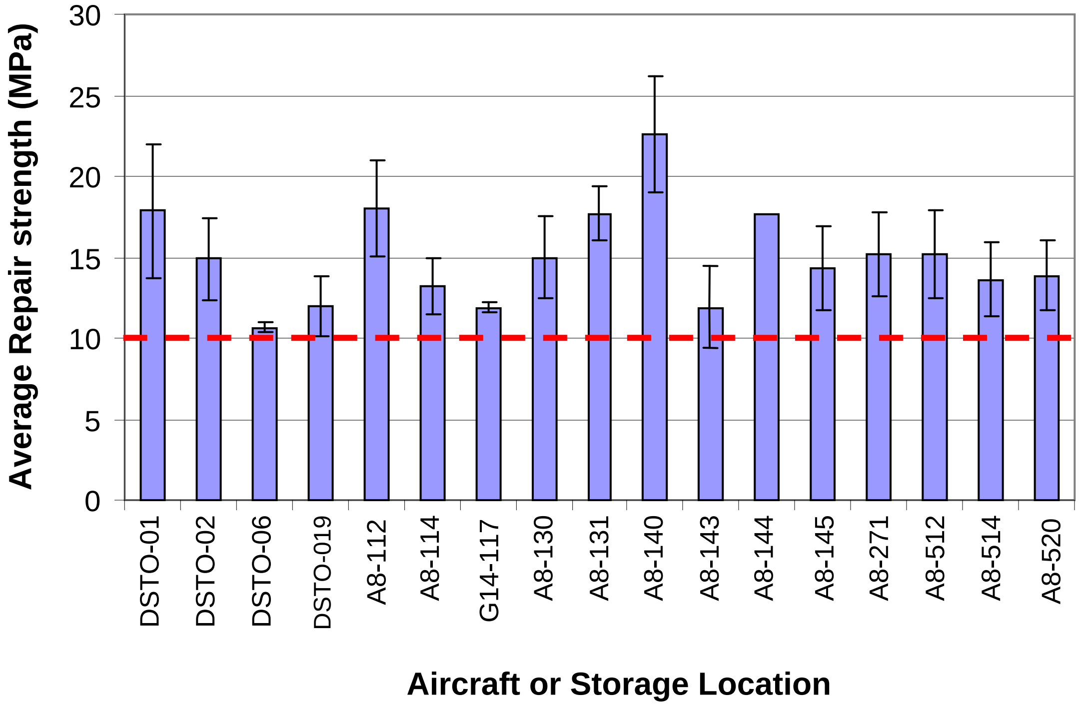

Figure 13 Average repair strength for each aircraft examined or for components recovered from storage locations. The dataset has stub results reported in Table 2 and repairs with only single measurements removed. The broken red line represents the lower limit expected for undegraded bonds accounting for possible geometrical variations in loading.

Specifically, repair number five from A8-143 had 10 pull stub tests carried out and 9 of the 10 tests from this repair had strengths below 10 MPa. The low strength repair location on panel 3208 was identified in Figure 9. Table 3 shows a detailed analysis of each of the pull-stub tests from repair 5 on A8-143. It was noted that most stubs exhibited higher levels of voiding than were previously observed on average strength stubs and that some evidence of adhesion failure was noted, shown in Figure 14. The strength below 10 MPa is believed to represent a reduction in strength from the typically applied repair, with high voiding levels suggesting deficiency in the application process, whereby either high humidity levels may have existed during application or inadequate drying procedures were employed. It is believed that the adhesion failure observed is a direct result of the high voiding levels. As only the stubs were available for detailed examination, it is difficult to tell whether moisture induced degradation was also present.

Note, this repair and many others that were later identified as having heavy voiding, had previously been cleared by non-destructive inspections (NDI) as being of acceptable quality. This illustrates how difficult it is to identify voiding in adhesive bondlines by tap testing and Bondmaster inspections, and even when more sensitive techniques such as ultrasonic scanning is used, there are limitations in transferring laboratory techniques to inspections in the field. A recent review of NDI techniques for composite materials covers some of the limitations of current and emerging technology [7].

Table 3 Details of repair number 5 from A8-143, which showed consistently low pull-stub strengths

Repair No.	Stub Id	Tap Test	Burst Pressure (psig)	Pull-Off Tensile Strength (MPa)	Failure Surface	Repair Environment/Age
A8-143 – 05 (Panel 3208, Nacelle outboard skin, Figure 9)	05A	Ok	17.2	9.7	Voiding	Application environment unknown. Accumulated hours and flight history unknown
	05B	Ok	15.3	8.6	Voiding, adhesion failure	
	05C	Ok	16.3	9.1	Adhesion failure	
	05D	Ok	12.9	7.2	Heavy voiding	
	05E	Ok	14.3	8.0	Heavy voiding	
	05F	Ok	17.2	9.7	Heavy voiding	
	05G	Ok	16.6	9.3	Heavy voiding	
	05H	Ok	9.6	5.4	Heavy voiding	
	05I	Ok	11.2	6.3	Heavy voiding	
	05J	Ok	18.7	10.5	Heavy voiding	

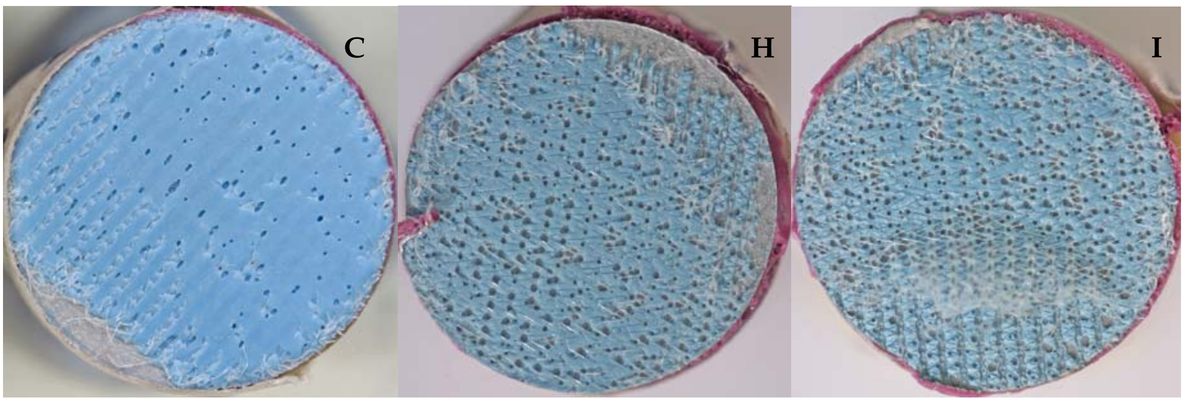

Figure 14 Test stubs C, H and I from repair A8-143-05. "C" shows the smooth surface typical of adhesion failure, while H and I show heavy voiding.

Figure 15 shows the average repair strength as a function of total repair age for the modified dataset where individual stub results from Table 2 were removed from the original dataset, as well as any repairs where only a single adhesion stub was tested. The results show that the average repair strength across the 15 years is around 15 MPa with a 95% confidence limit of ±3 MPa. The confidence limit is only marginally lower than the unprocessed data but suggests that, if accounting for anomalous results and statistically limited data, the lowest probable strength would be 12 MPa. When accounting for the weak trend in data, which suggests some reduction of bond strength with time, the likely strength of a new adhesive bonded repair would be approximately 17 MPa, and after more than 15 years exposure the strength could drop by only 12% on average. The data provides an encouraging indication that the strength of the bonded repairs does not appear to be significantly affected over a considerable period of time. Generally, the spread in data appears to be relatively consistent over the period of the analysis, which suggests that this variability in strength measurements is inherent in the intrinsic strength of the repairs, as applied, as well as the measurement techniques used. It should also be noted that the data filtering applied has reduced the original dataset from 236 to 163 repairs and then of those repairs only 62 had recorded application dates, but given the similar trends observed in Figure 10 and Figure 15, there is some confidence that the overall analysis is representative of a larger dataset.

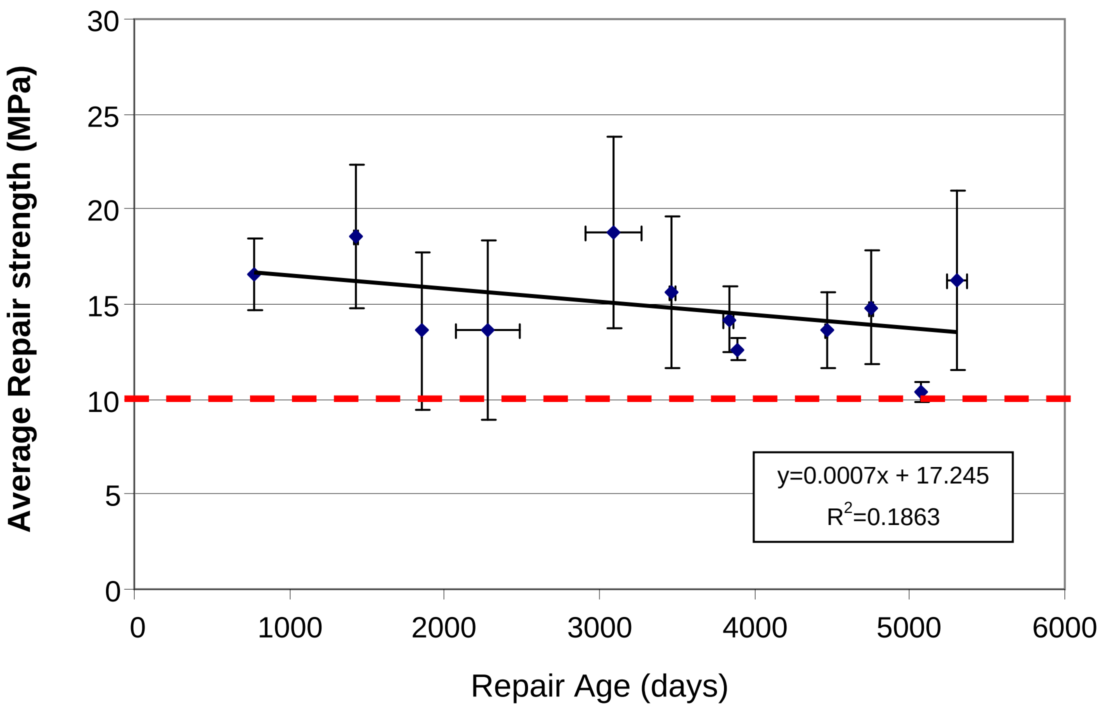

Figure 15 The average repair strength as a function of total accumulated time since application, where individual stub results from Table 2 were removed from the original dataset as well as any repairs where only a single adhesion stub was tested. The broken red line represents the lower limit expected for undegraded bonds accounting for possible geometrical variations in loading.

Further analysis of the dataset in Figure 15 examined the trend in repairs where the flight hours was confidently known through review of available paperwork. This reduced the number of repairs further to 43. However, it can be seen that the trend in Figure 16 is similar to Figure 15 and Figure 10, with average repair strengths over the 1500 flight hours of data having similar average values and similar confidence limits. The average strength is 16 MPa with a 95% confidence interval around ±3 MPa. No repairs have average strength values below 12 MPa, which provides confidence that flight hours do not significantly affect the strength of the bonded repairs. Similarly, strength variation is relatively similar for the range of times examined, suggesting the variation is inherent in the repairs and measurement techniques used. A8-112 aircraft had one repair, number 29, with an average value of 9.8 MPa corresponding to 224 flight hours. Two stub results at 8.5 and 9.3 MPa showed similar failure surfaces to those described in Table 3, with higher levels of porosity and evidence of adhesion failure. Once again, it appears that the slightly lower strength results recorded for these stubs is a genuine indication of a reduced bond strength from average and is likely due to inadequacies associated with original application. There were no signs of degradation associated with moisture absorption of the bondline.

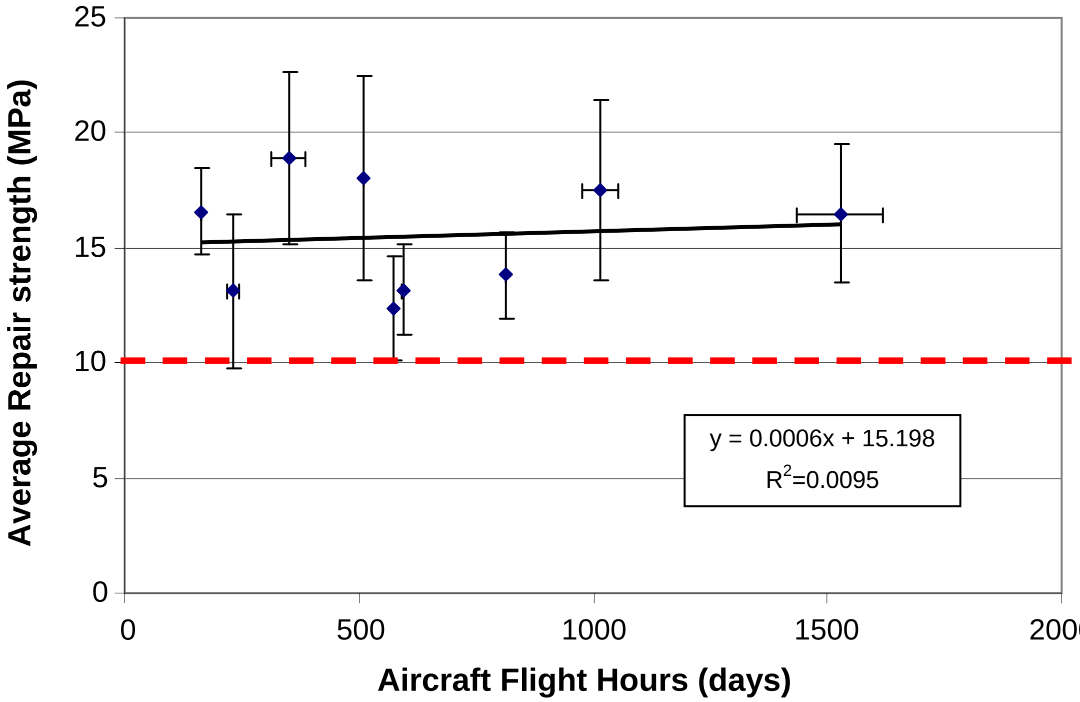

Figure 16 Only repairs with a traceable service history have been included in this data set. This reduced the number of repairs to 43.

4.2.5 Detailed Analysis of Low Strength Pull Stubs

As indicated in the statistical analysis above, the average bonded repair strength in a single repair may overlook the case where low individual stub strengths exist when the overall repair strength is satisfactory. Consequently, all cases in the filtered data shown in

Figure 13 were examined where stub strengths were below 10 MPa. Table 4 shows results for individual stub results used to calculate the average repair strength. The individual pull-stub strengths below 10 MPa have failure causes detailed.

The reasons for the reduction in strength of individual stubs can be classified into four broad areas: 1) Corrosion 2) Heavy Voiding 3) Poor adhesive wetting and 4) Poor grit-blasting. If the results from Table 3 and Table 4 are combined this provides a total of 52 stubs in which there were indications present on 34 stubs.

Table 4 Details of individual pull-stub measurements where the strength was below 10 MPa for the FM300 repair dataset which was filtered for single measurement repairs and anomalous results detailed in Table 2.

Aircraft	Repair No.-Stub	Stub Strength (MPa)	Failure Surface Stub	Repair Environment/ Age	Failure Surface Repair
A8-112	12A	17.2	OK	unknown/ 3436h/350afhr	Small areas throughout where adhesive wetting is poor
	12B	6.0	Poor adhesive wetting		
	12C	18.8	OK		
	29A	10.7	Heavy voids with areas of adhesion failure which may be associated with early corrosion (aluminium residue present)	within limits/ 1851h/224afhr	Patch shows high levels of voiding with evidence of adhesion failure and onset of corrosion
	29B	10.8			
	29C	8.5			
	29D	9.3			
A8-114	01A	7.2	areas of adhesion failure may be associated with early corrosion (aluminium residue present)	unknown/ unknown	Patch generally has cohesive failure with small areas of adhesion failure and onset of corrosion
	01B	13.1	OK		
	06A	12.2	OK	unknown/ unknown	Weak regions exhibit high void levels and localised regions near core where adhesive wetting is poor suggesting pressurisation problems
	06B	6.8	Very heavy void lines		
	06C	3.1	Poor adhesive wetting		
	06D	40.4	OK		
	06E	6.7	Poor adhesive wetting		
	22A	7.9	Adhesion failure: Insufficient grit-blast	unknown/ unknown	Large void tracks emanate from central core region suggesting inadequate drying and volatile removal prior to bonding
	22B	7.6	Very heavy void lines		
	22C	8.9	OK		
	22D	12.5	OK		
A8-130	18A	5.9	High voids	unknown/ unknown	Repair has localised voiding in area where low pull-stub strength recorded
	18B	11.0	OK		
A8-143	05A-05J	Refer Table 3			
	08A	17.1	OK	within limits/ 2381h/255afhr	Large void tracks emanate from central core region suggesting inadequate drying and volatile removal prior to bonding
	08B	8.5	Very heavy void lines		
	08C	7.1	Very heavy void lines		
	08D	11.1	voids		

Table 4 cont'd Details of individual pull-stub measurements where the strength was below 10 MPa for the FM300 repair dataset which was filtered for single measurement repairs and anomalous results detailed in Table 2.

<table>
<tr><th>Aircraft</th><th>Repair No.-Stub</th><th>Stub Strength (MPa)</th><th>Failure Surface Stub</th><th>Repair Environment/Age</th><th>Failure Surface Repair</th></tr>
<tr><td>A8-145</td><td>29A</td><td>8.2</td><td>Adhesion failure: Insufficient grit-blast</td><td rowspan="3">unknown/ unknown</td><td rowspan="3">Patchy surface preparation shows variability in grit-blast quality leading to adhesion failure</td></tr>
<tr><td></td><td>29B</td><td>12.8</td><td>OK</td></tr>
<tr><td></td><td>29C</td><td>9.0</td><td>Adhesion failure: Insufficient grit-blast</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>A8-271</td><td>20A</td><td>9.1</td><td>OK</td><td rowspan="2">unknown/ unknown (aircraft out of service 4 years before inspection)</td><td rowspan="2">Patchy surface preparation shows variability in grit-blast quality leading to localised adhesion failure</td></tr>
<tr><td></td><td>20B</td><td>6.4</td><td>Adhesion failure: Insufficient grit-blast</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="13">A8-514</td><td>01A</td><td>13.3</td><td>OK</td><td rowspan="3">unknown/ 5072h/unk.</td><td rowspan="3">Localise corrosion present throughout repair and surrounding structure</td></tr>
<tr><td>01B</td><td>11.3</td><td>OK</td></tr>
<tr><td>01C</td><td>5.0</td><td>Corrosion</td></tr>
<tr><td>07A</td><td>11.9</td><td>OK</td><td rowspan="3">unknown/ 3849h/813afhr</td><td rowspan="3">Patch generally has cohesive failure with small areas of adhesion failure associated with onset of corrosion.</td></tr>
<tr><td>07B</td><td>6.4</td><td>Adhesion failure and corrosion</td></tr>
<tr><td>07C</td><td>14.1</td><td>OK</td></tr>
<tr><td>11C</td><td>22.3</td><td>OK</td><td rowspan="2">unknown/ unknown</td><td rowspan="2">Highly localised corrosion</td></tr>
<tr><td>11D</td><td>1.5</td><td>Corrosion</td></tr>
<tr><td>21A</td><td>8.8</td><td>Adhesion failure and corrosion</td><td rowspan="3">unknown/ unknown</td><td rowspan="3">areas of adhesion failure which may be associated with early corrosion (aluminium residue present)</td></tr>
<tr><td>21B</td><td>12.2</td><td>OK</td></tr>
<tr><td>21C</td><td>6.9</td><td>Adhesion failure and corrosion</td></tr>
<tr><td>23A</td><td>16.6</td><td>OK</td><td rowspan="2">unknown/ 5334h/1001afhr</td><td rowspan="2">Localised areas of voiding</td></tr>
<tr><td>23B</td><td>6.4</td><td>voiding</td></tr>
</table>

A total of 21 stubs showed heavy voiding associated with lines or tracks that had emanated from the central core region. These indications are highlighted in green in Table 3 and Table 4. A core repair requires cleaning by solvent flushing, followed by drying to remove the solvent. The heavy void tracks, an example of which is shown in Figure 17, are indicative that inadequate drying of the core had occurred prior to the elevated temperature cure of the FM300.

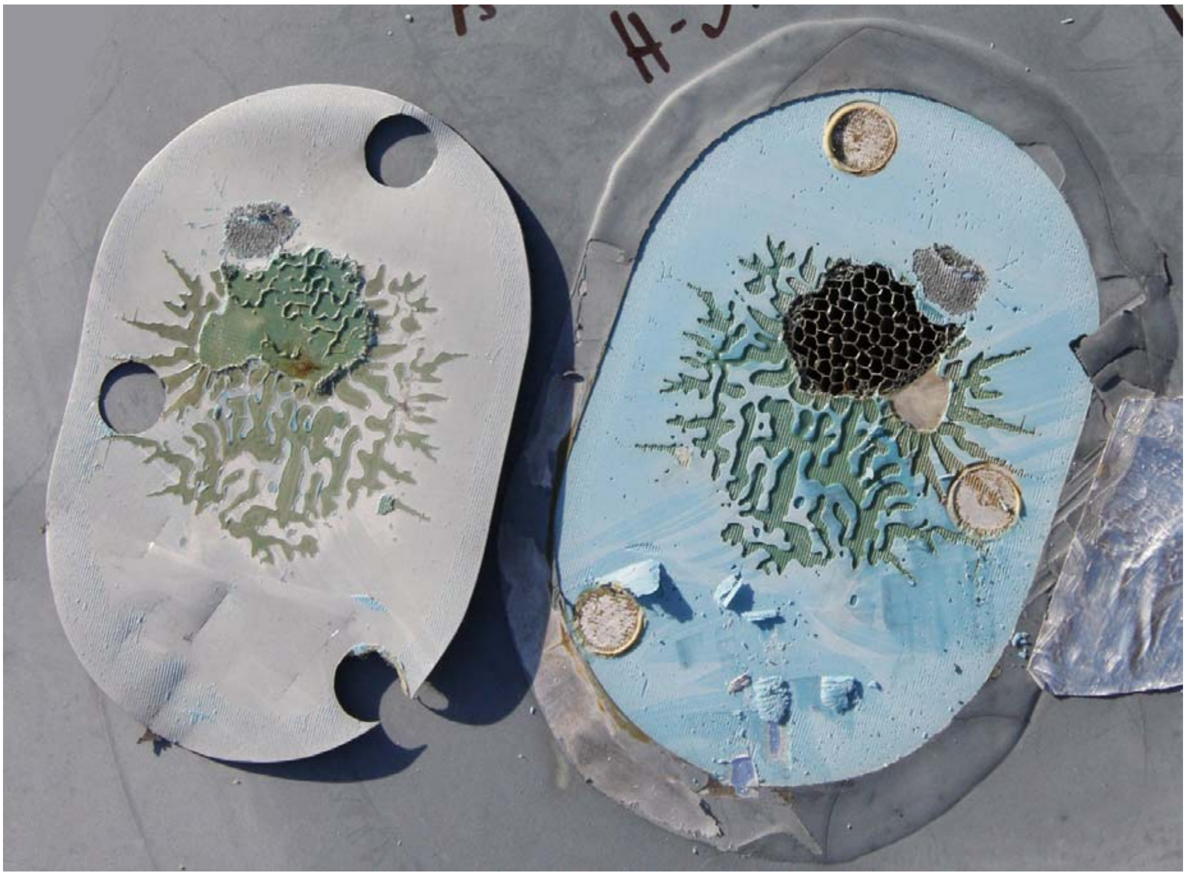

Figure 17 Repair 514-28 shows heavy voiding emanating from the repaired core, indicative of inadequate drying following cleaning.

There were 6 stubs which indicated localised corrosion had occurred, including the lowest stub strength recorded for the filtered dataset, which was stub 11D on A8-514. Photographs of the test stub are shown in Figure 18. Inspection of this repair indicated that corrosion was in a very localised area where the low strength stub was pulled, whereas the stub pulled in an area representative of the unaffected region had a strength over 20 MPa. This indicates that the overall repair strength was satisfactory, but localised corrosion had led to significant bond strength reduction. Potentially, the long term storage of the aircraft in an outdoor location, and a long period without maintenance prior to the repair inspection (records indicate that the aircraft had been taken out of service seven years prior to inspection), had led to the corrosion of the repair due to deterioration of the protective paint layer and sealant. Nevertheless, the localised corrosion has clearly developed at a very slow rate and would be identified readily during normal maintenance of the aircraft.

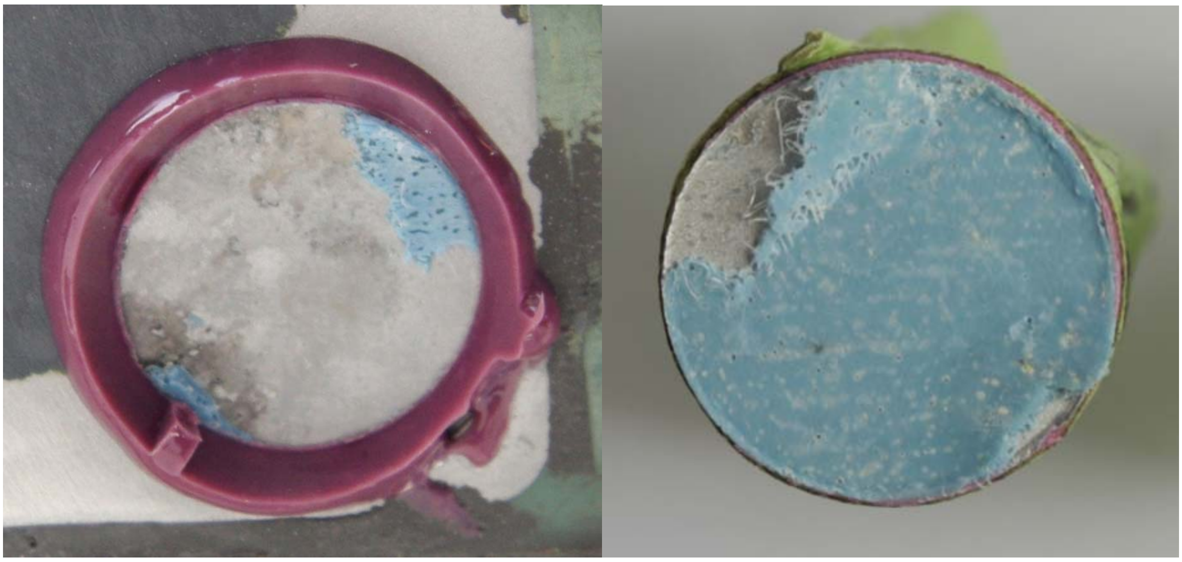

Figure 18 Test area exhibiting corrosion (stub 11D on A8-514). The aircraft side is shown on the left, and the test stub (removed doubler) on the right.

There were 5 stubs that indicated there was onset of corrosion associated with high void levels in the adhesive, highlighted in orange in Table 4. This may identify, that in cases of extreme voiding, the high porosity provides easier access for moisture into the bondline, facilitating corrosion. Whilst the high porosity stubs that showed onset of corrosion generally had reasonable bond strengths around 10 MPa, this identifies potential long term problems that may be caused by porous bondlines.

Amongst the lowest strengths observed were stubs for which there were apparent adhesive wetting problems, highlighted in blue in Table 4. Cases where the adhesive has not wetted either the doubler or aircraft skin are indicative of inadequate vacuum pressure being applied during the repair. An example is shown in Figure 19. In this particular repair, the adhesive has not come into contact with the aircraft skin in the area immediately to the right of the core insert. In other areas, such as the enlarged view of one test area and matching stub, the adhesive has come in contact with both faces but has wetted poorly. The low strength of these areas suggests that whilst it was relatively unusual, poor wetting was one of the more serious problems that could affect overall repair strength.

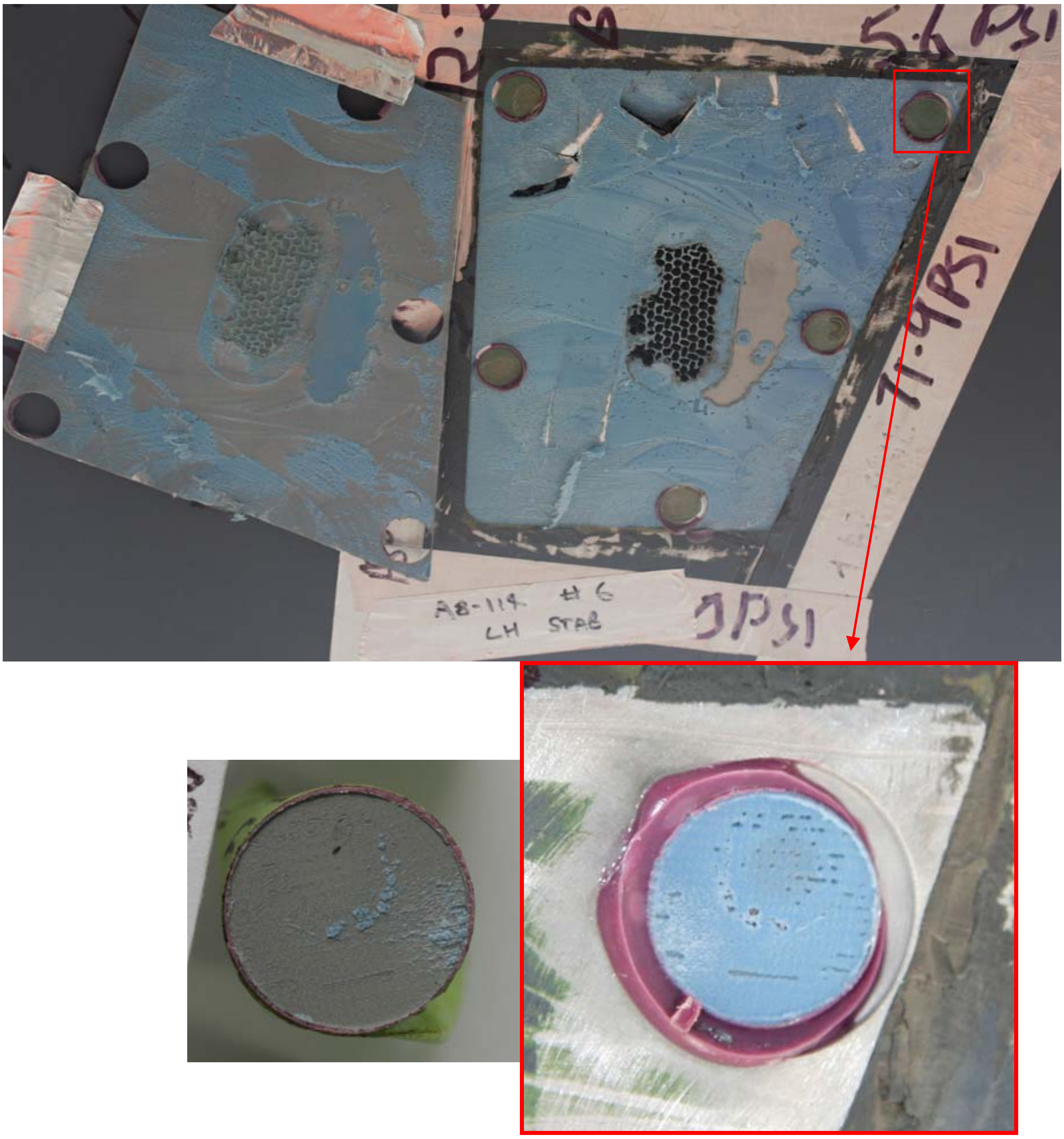

Figure 19 An example of poor wetting, with bare aluminium shown to the right of the core insert. In other areas the adhesive has come in contact with both faces but has wetted poorly.

The final category of fracture surface identified, leading to lower localised repair strength, was observed for regions where the grit-blasting coverage appeared to be inadequate, highlighted by grey in Table 4. An example is shown in Figure 20, where Scotchbrite abrasion lines are clearly visible, suggesting that the level of grit-blasting was inadequate. Whilst the lightly grit-blasted region led to a clear reduction in stub strength, it did not appear to be the cause of the lowest strength reductions. The causes of low grit-blast coverage could potentially be related to difficulties with the equipment, which has been identified previously for wedge test samples prepared at Amberley over a number of years [8]. An inspection tool, the BYK Gardner Micro TRI Gloss® gloss-meter, had previously been identified as being suitable for indicating whether aluminium surfaces have been adequately grit-blasted as part of the RAAF process for preparing adhesively bonded repairs [9]. Incorporation of this tool in pre-bond quality assurance testing would be expected to improve the quality of adhesively bonded repairs.

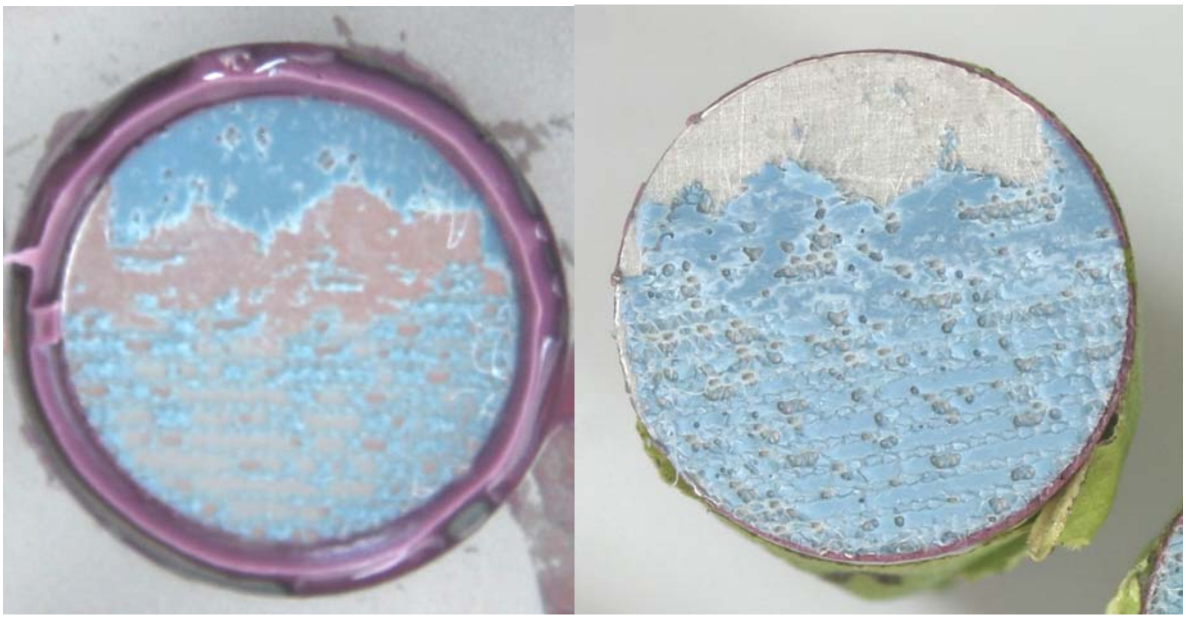

Figure 20 Test 145-29A, aircraft side on the left, and test stub (doubler) on the right. Close inspection of the test stub reveals Scotchbrite abrasion lines, suggesting that the level of grit-blasting was inadequate.

A summary of the failure indications and the average strength associated with each type is provided in Figure 21. The results indicate the average strength for each indication type, with the spread in data shown by error bars, which represent the 95% confidence limits. The plot provides a useful measure of the relative severity of each type of failure with respect to the reduction in the overall stub strength in the locally affected areas. Both corrosion damage and poor adhesive wetting of the aluminium surfaces leads to significant decreases in strength, indicating identification of these defects would have the highest priority in repair inspection and maintenance. The poor grit-blasting also causes reduction in strength, but together with high voiding does not appear to lead to as significant reductions as corrosion and wetting, but would be important to identify in any post repair inspections. Interestingly, the areas of the repair without any indications provided average strengths and deviations that are very similar to the average values determined in Figure 15 and Figure 16. This suggests that average repair strengths for the filtered data represent the significant majority of the total repair areas examined, with degradation in strength being confined to relatively localised regions. Generally, this would imply that no single repair had significant levels of strength reduction associated with long term environmental or service exposure.

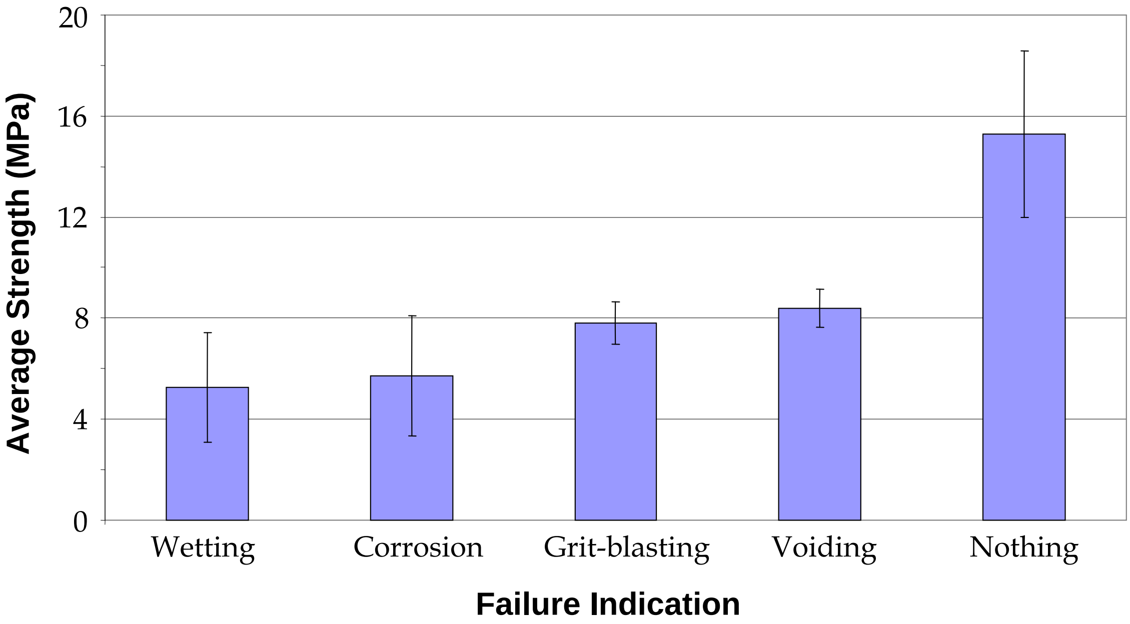

Figure 21 Average strength for individual pull-stubs with failure indications categorised according to problems with adhesive wetting (wetting), localised corrosion (corrosion), inadequate grit-blasting (grit-blasting) and high levels of voiding (voiding). The strengths are compared to stubs measured on the same repairs without any indications (nothing).

5. Conclusion

The following conclusions can be drawn from the analysis of the bonded repairs carried out on F-111 honeycomb structure using FM300 adhesive using the PATTI test to assess residual bond strength:

1) The PATTI test shows some sensitivity to both piston misalignment and substrate thickness, which leads to an effective lowering of the bond strength for a fully intact bond.
2) Based on an assessment of the available data from the field testing of repairs, combined with laboratory trials, it was determined that a full strength repair should normally exceed 10 MPa in pull-off tensile strength.
3) The PATTI test has provided a reliable method for screening a large number of adhesive bonded repairs conducted on the F-111 honeycomb panels over more than 15 years and generally could identify cases where repair strength was reduced relative to average baseline strength.

4) The trend in the overall dataset was consistent before and after various filtering was applied, providing confidence that the conclusions drawn could be related to a larger repair population.
5) When the PATTI test results were filtered for statistically significant numbers of tests and erroneous results, it was clear that the bond strength of repairs was not affected by either service life or total accumulated hours since application.
6) The range in repair strengths across more than 15 years of life was relatively similar, which is indicative of variability associated with the repair application process or the strength measurement methods employed.
7) The trend in repair strength with repair age suggests that over a 15 year period there will be an average strength around 15 MPa with a 95% confidence limit of ±3 MPa. This is very similar to the values determined for repairs with more than 1500 accumulated flight hours.
8) An examination of low strength stubs, which represented localised regions of degraded repair strength, identified four general causes: Localised corrosion, poor adhesive wetting, high bondline voiding or porosity and inadequate grit-blasting. Corrosion and poor adhesive wetting were identified as the most serious cases, leading to significant reductions in bond strength.
9) The analysis of FM300 adhesively bonded repairs conducted on F-111 honeycomb panels suggests that repairs have been applied reliably over a number of years, leading to good strength bonds with limited evidence of long term degradation associated with environmental exposure experienced during storage or flight.
10) The current results provide additional confidence in the current RAAF methods used to apply adhesively bonded repairs to aluminium structures when trained technicians undertake the repairs in fit-for-purpose facilities.

6. Recommendations

Based on the analysis of the patches examined using the PATTI test, combined with failure surface examination, the following recommendations are provided:

1) Non-destructive techniques should be employed or developed which will enable the inspection of repairs directly after application that can verify the level of porosity that exists in the bondline. Presently, techniques exist that can reliably achieve this in real world, on-aircraft applications, and a considerable number of repairs exhibit high levels of voiding or porosity, even in cases where the prescribed limits for humidity and temperature in the repair environment have been observed.
2) Repairs should be inspected during each major service for any signs of localised corrosion; evidence from the current study suggests that the bonded repairs do not corrode rapidly and typically corrode in localised areas at the doubler perimeter.

This indicates that regular inspection would identify localised degradation well before the overall repair had degraded in strength.

3) Efforts to incorporate prebond quality assurance should be examined to ensure processes such as uniform grit-blasting are carried out adequately, given there are signs that poor grit-blast coverage has led to areas of lower strength on some repairs.

4) The results from the current program should be incorporated into the current DEFAUST9005 RAAF publication so as to provide engineers involved in the bonded repair of aircraft structures with an indication of the reliability and expected longevity of repairs carried out using methods specified in AAP7021.016-1 and AAP7021.016-2 publications.

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19. ABSTRACT

It is estimated that over 5,000 adhesively bonded repairs (ABRs) have been applied to the Royal Australian Air Force (RAAF) F-111 aircraft over the last twenty five years, mainly to honeycomb sandwich panels. Retirement of the fleet in December 2010 presented a unique opportunity to evaluate the integrity of a large number of airworthy ABRs. Consequently, DSTO in partnership with the RAAF, through ASI at DGTA and with the assistance of Boeing Australia developed a program to assess the condition of the F-111 ABRs. The F-111 Adhesive Bonded Repair Assessment Program (FABRAP) was established in mid 2010 and initial field testing was carried out from October 2010. The current report provides an update on the analysis of the results from the field level testing undertaken between October 2010 and May 2011 on repairs to honeycomb structure which used FM300 adhesive and RAAF approved surface treatments and application procedures.

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